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INTRODUCTION

There are numerous factors which define the upper usable limit of high temperature metal alloys. The most prominent factors are strength and stiffness degradation at elevated temperatures. Another factor that imposes design limitations is high temperature creep. A structure operating at stress and temperature combinations within the creep range of the material can result in failure, excessive deformations, or serious residual stresses. Designers have generally avoided the creep range by a wide margin because of the serious consequences of unanticipated creep. The margin of avoidance has been quite large because of uncertainties in the ability to predict creep in complex built-up structures. One of the major factors inhibiting development of predictive methods lies in the scarcity of experimental creep data for built-up structures. Without experimental data to correlate with predictive techniques, the development and refinement of these techniques is redundant or at best incomplete.

The intent of this report is to provide measured laboratory data of creep in a complex built-up structure subjected to heating and mechanical loading. A very detailed description of the experimental structure and the experiment set-up is presented. A built-up test structure of aluminum and titanium alloys is heated and loaded such that the combined mechanical and thermal stresses are large enough to cause creep in the heated skins of the structure. Time-histories of temperature, strains, and deformations will be presented in plotted form.

DESCRIPTION OF TEST SPECIMEN AND INSTRUMENTATION

A cross-sectional drawing of the test specimen is presented in figure 1. The specimen is typically a skin/substructure type of structure. The .0063 meter (.25 inch) thick skin is 2024 aluminum alloy in the T3 condition. The substructural frames are fabricated of .0013 meter (.050 inch) 6Al-4V titanium alloy sheet and .0114 meter (.450 inch) 6Al-4V titanium alloy material. The sheet was formed to a zee-shape and attached with fasteners to the skin at the top and to the lower cap at the bottom. The skin is a continuous sheet with no joints. The overall length of the test area of the specimen is 1.219 meter (48.0 inches).

A schematic of the test set-up is shown in figure 2. The continuous length of the specimen and the loading bar is 3.581 meters (141.0 inches) from pinned end to pinned end. Loads are applied to the specimen at each of the frames through a system of hydraulic jacks located 0.914 meters (36.0 inches) inside of the pinned ends. This loading approach results in a constant bending moment applied to the specimen from jack location to jack location. Heating is applied to the top of the specimen (skin side) by a system of radiant heat lamps. Areas other than the 1.219 meter (48.0 inch) test portion are shielded from the heating by a system of heat shields.

The basic method of the test is to apply heat to the skin for the purpose of: (1) creating compressive thermal stresses in the skin area, and (2) elevating the skin temperature such that creep can occur more readily in the skin. The purpose of the loading system is to cause a compressive stress in the skin area to augment the compressive thermal stresses. The magnitude of the applied load is selected so that the combined mechanical load skin stresses and the skin thermal stresses are of such magnitude that significant creep occurs due to the combination of stress and temperature of the skin. Aluminum was selected as the skin material and titanium as the substructure material because of their great dissimilarity in coefficients of thermal expansion. The aluminum skin has a coefficient of thermal expansion (reference 1) approximately three times as large as the titanium alloy. This dissimilarity aided in achieving a large component of compressive thermal stress.

The specimen was extensively instrumented with strain gages and thermocouples. Strain gages on the skin were arranged in both equiangular rosettes and tee configurations so that biaxial stress situations and principal stresses could be accommodated. Strain gages located on the frames were arranged in tee configurations so that axial stresses could be measured. Chromel-alumel thermocouples were spot welded at the same locations as the strain gages. The location of the instrumentation is shown in figure 3. The number of the sensor is identified and the longitudinal station at which the sensor is located follows the sensor number. Thermocouples are identified by the number and a letter following. A thermocouple may be identified as the number 12, typically, which could be located on the drawing in figure 3. A strain gage at location 12 might be identified as 12A (axial orientation), 12T (transverse orientation), 12B (sixty degree rosette orientation), or 12C (one hundred twenty degree orientation). A tee-gage would have two strain gages which would be identified typically as

12A and 12T. A rosette would have three strain gages which would be identified typically as 12A, 12B, and 12C. A photograph of the instrumentation is shown as it is installed on the specimen in figure 4.

EXPERIMENTAL PROCEDURE

A photograph of the experimental set-up is shown in figure 5. A sketch depicting the time-history of a skin strain gage is presented in figure 6. This sketch is a very comprehensive way to explain the procedure of the experiment in terms of what is happening to the specimen. The experiment can be best described by starting at point A (figure 6). At this initial time, the heating of the upper skin surface begins. The heating is accomplished by raising the skin temperature to 533 K (500°F) and holding the skin at this temperature. Since only the upper surface of the skin is heated, then as time progresses, heat is transferred to the frames attached to the unheated side of the skin. At some later time, point B, the heat transfer has reached a near steady state and the thermal stresses (which are causing the early strain measurements) become non-transient. After the thermal stresses are no longer changing with time, loads are applied to the specimen with the system of hydraulic jacks and a corresponding increase in strain is seen (from point B to point C). A schedule of loads is presented in Table I. At point C the specimen is under load from two sources: (1) thermal stresses resulting from the non-uniform temperature field, and (2) bending stresses resulting from the applied mechanical forces. The object of the experiment is to make the skin creep. The skin at time C is experiencing compressive thermal stresses and compressive bending stresses.

At point C the skin is at a temperature and stress level such that creep of the skin will begin to occur. The increase in strain that occurs between points C and D is due to creep effects. At point D the load is reduced to sixty percent so that a different creep rate can be recorded between points D and E. At point E the load is increased to eighty percent so that the creep rate at that load level can be experienced between points E and F. At point F the load is removed from the specimen and at point G the heating is terminated. At point H the specimen has cooled down to room temperature and the strain that remains is a residual the content of which will be discussed in later sections.

RESULTS AND DISCUSSION

Three types of data have been generated from the creep experiment described in this paper: (1) temperatures, (2) strains, and (3) deflections. Since a single test of approximately six hours duration was conducted, the data are presented in time-history format.

Temperature data are presented in figure 7. Figures 7(a) and 7(b) are time-histories of thermocouples located on the skin. Thermocouples 80, 800, 90, and 900 are located near the shielded ends of the test area, hence, these temperatures are lower than other skin thermocouples. The temperature data shown in figures 7(c) through 7(f) are thermocouples located on the substructure frames 1 through 4 (see figure 3).

Strain data for the equiangular rosettes on the skin are presented in figure 8. The A, B, and C legs, as described in the Description of Test Specimen and Instrumentation Section, are presented for the strain gages located at the three skin locations. The time-history of strain as depicted in figure 6 can be followed clearly. The gradual increase in strain due to thermal stress and the leveling off as the temperature distribution stabilizes can be seen. The sudden jump in strain when the 100 percent load is applied and the gradual change due to creep is also clear. The reduction to 60 percent load with the lower creep rate and the increase to 80 percent load with the higher creep rate can also be distinctly seen. The final events include removing the load, terminating the heating, and observing the residual strain resulting from the creep effects.

Skin strain gages arranged in a tee configuration are presented in figure 9. The axial (A-gage) sensor is oriented in the same direction as the axis of the frames. The transverse gage is oriented lateral to the axial gage and in the plane of the skin. The pattern depicted in figure 6 is seen for this set of strain gages. The gages nearest the ends of the specimen (90 and 900) are seen to have smaller strains than the other tee gages.

Time-histories of strains in the substructural frames are presented in figures 10 through 13. Strain data was taken from gages in the tee configuration with the A leg oriented in the direction of the axis of the frame. The strains in the axial direction are primarily tensile in nature.

Mid-span deflection of the two outer frames (frames 1 and 4) are presented in figure 14. When the heat is applied to the skin, the structure deflects toward the heaters (positive deflection is up). The down loads applied to the specimen result in downward deflection. The other events during the test can similarly be seen in figure 14. It should be noted that the residual strains result in little residual deflections.

Examination of all the strain data shows residual strains at the conclusion of the test. The significance of this residual strain is seen in figure 15 where residual stress distributions are presented for the four frames. Although the stresses are not large in terms of the yield strength of the material they are very important from an elastic stability aspect. Almost all of the web part of the frame experiences compressive stresses. The web is a relatively thin member, .0013 meter (.050 inch), hence, it is highly susceptible to buckling under compressive stresses. Establishing the buckling strength of the webs of the frame with the loading shown in figure 15 is not a straightforward task. It was estimated that the compressive residual stresses resulting from the experiment were of such magnitude that additional experimentation might result in failure or damage to the frames. Hence, only one creep experiment was conducted on this specimen.

The information that has been presented provides an experimental data base that the reader may use to test various temperature, stress, and creep prediction methods for built-up structures. The primary thrust of this report is to disseminate creep experimental data for a structure exposed to heating and loading. Hence, the detailed description of the specimen and the experiment is provided. The basic data (temperature, strains, and deflections) resulting from the experiment is presented.

CONCLUDING REMARKS

Experimental creep, temperature, and strain data resulting from a laboratory experiment on a built-up aluminum/titanium structure has been presented. The structure and the experiment are described in detail. A heating and loading experiment lasting approximately six hours was conducted on the test structure. Considerable creep strain resulted from compressive stresses in the heated skin. Large residual stresses were found after the experiment was completed. The residual stresses in the substructure frames were large enough to preclude further cycles of creep experiments with this built-up structure because of concern that the frame webs would buckle.

NASA Ames Research Center
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October 20, 1982

REFERENCES

1. Aerospace Structural Metals Handbook. Volumes III and IV. ADML-TR-68-115, Air Force Materials Lab., Wright-Patterson AFB, 1978.

TABLE I - SCHEDULE OF LOADING

	100 Percent Load Newtons (pounds)	80 Percent Load Newtons (pounds)	60 Percent Load Newtons (pounds)
Frame 1	5591 (1257)	4472 (1006)	3352 (754)
Frame 2	6325 (1422)	5060 (1137)	3795 (853)
Frame 3	6210 (1396)	4968 (1116)	3726 (838)
Frame 4	5475 (1231)	4380 (985)	3285 (739)

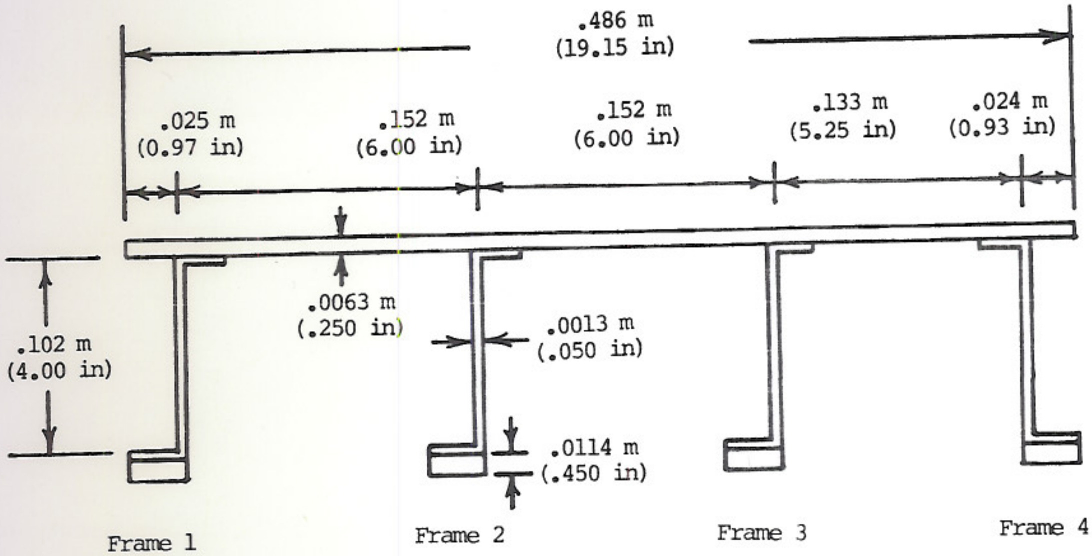


Figure 1. Test specimen cross-section.

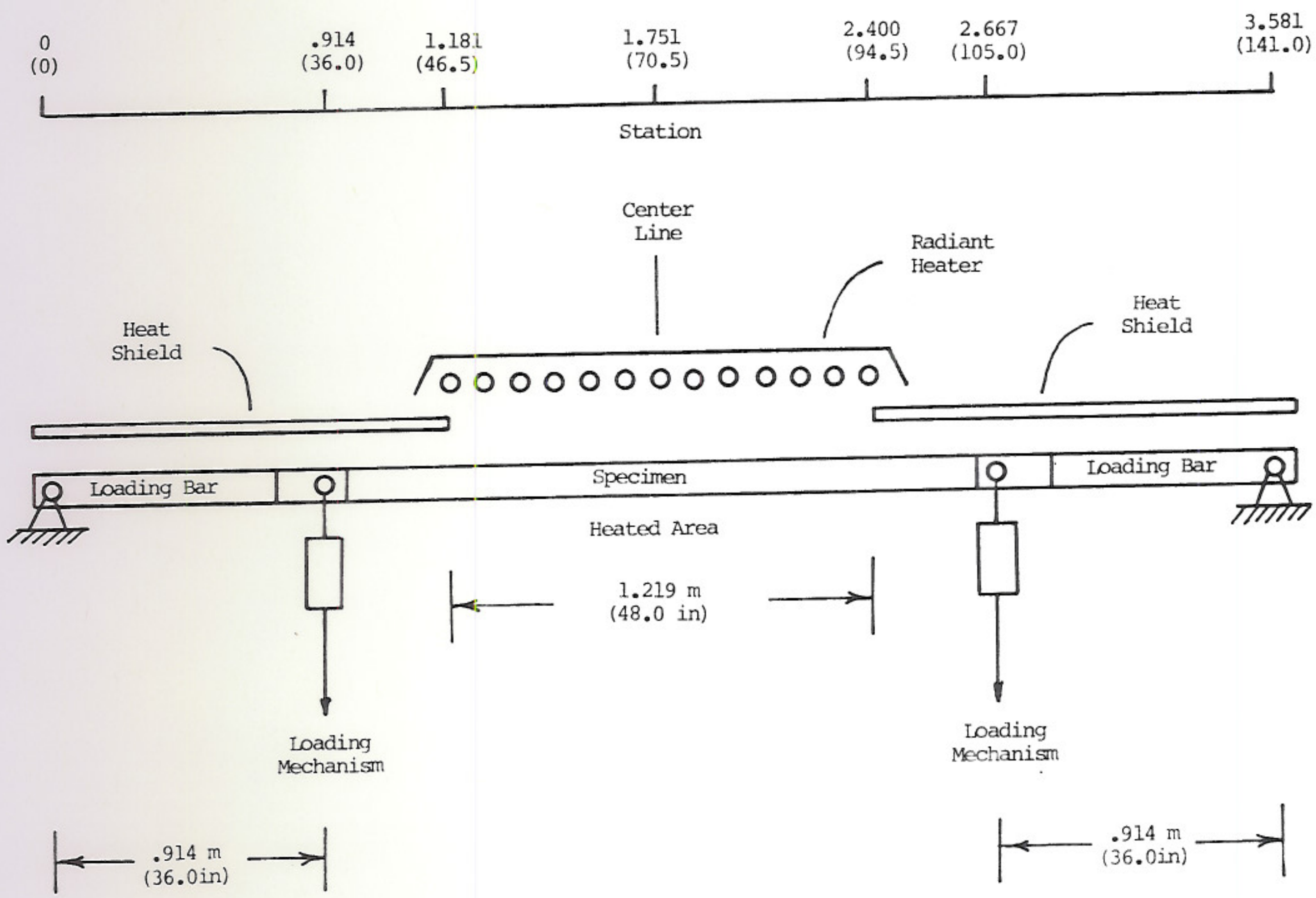


Figure 2. Test set-up schematic.

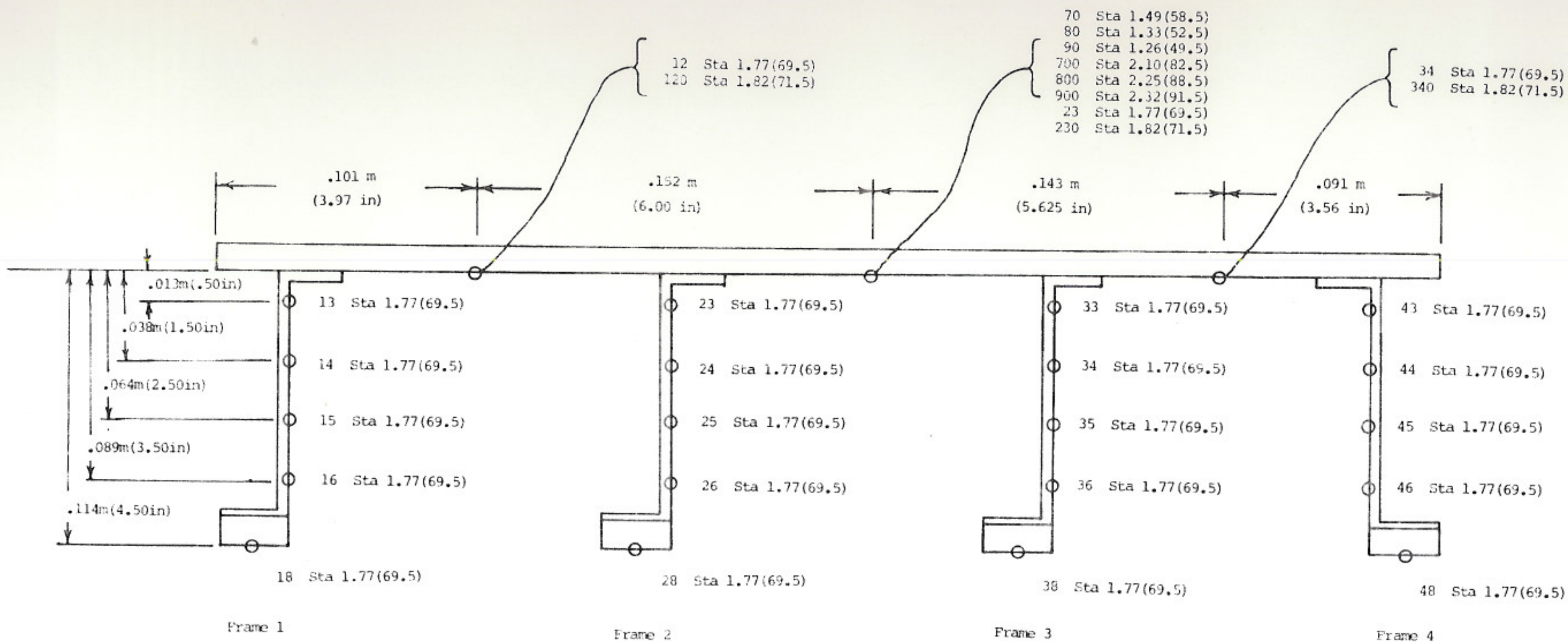
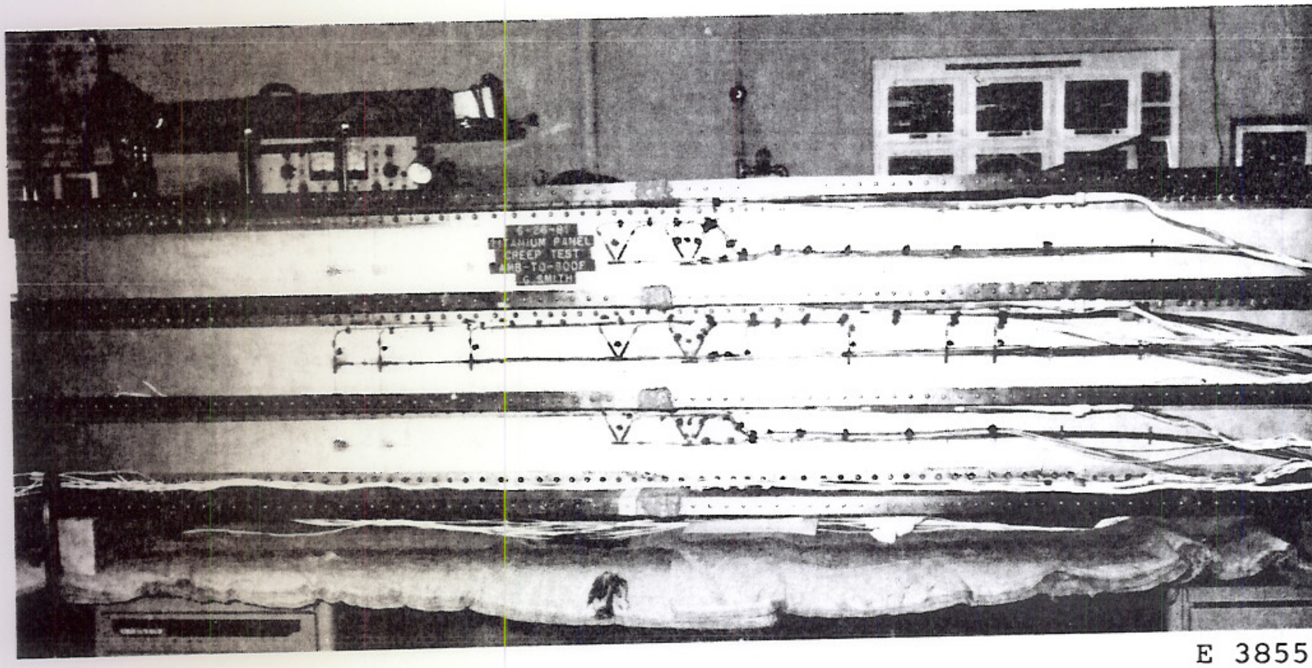
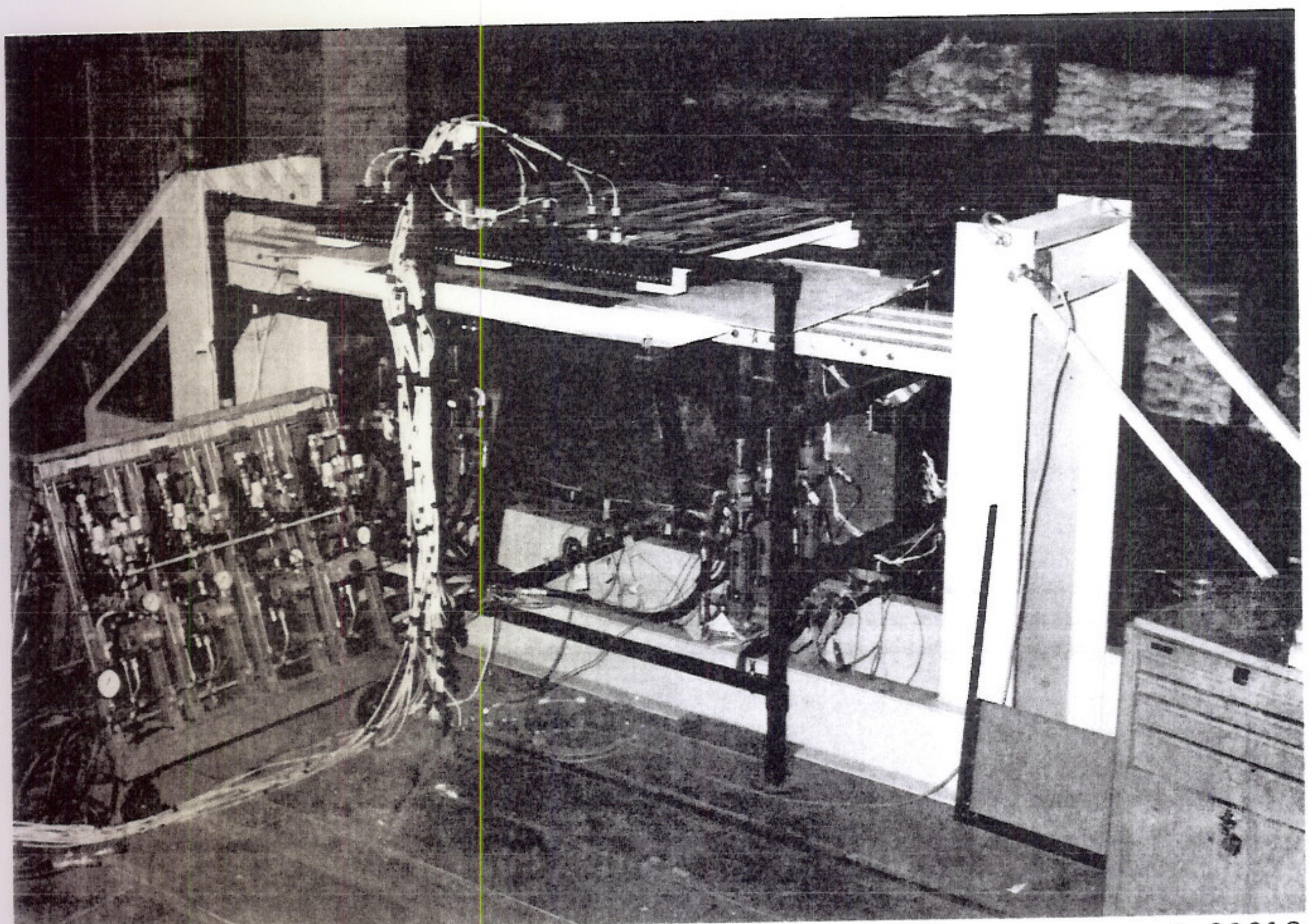


Figure 3. Instrumentation location.



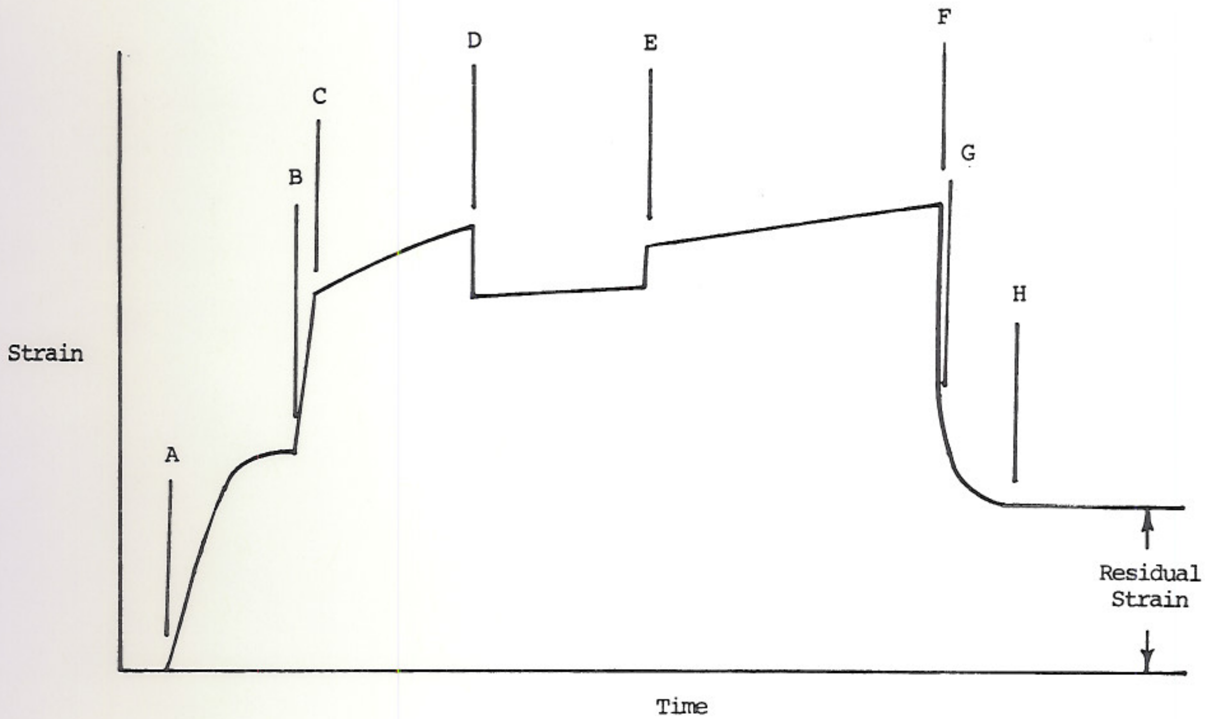
E 38552

Figure 4. Photograph of instrumentation.



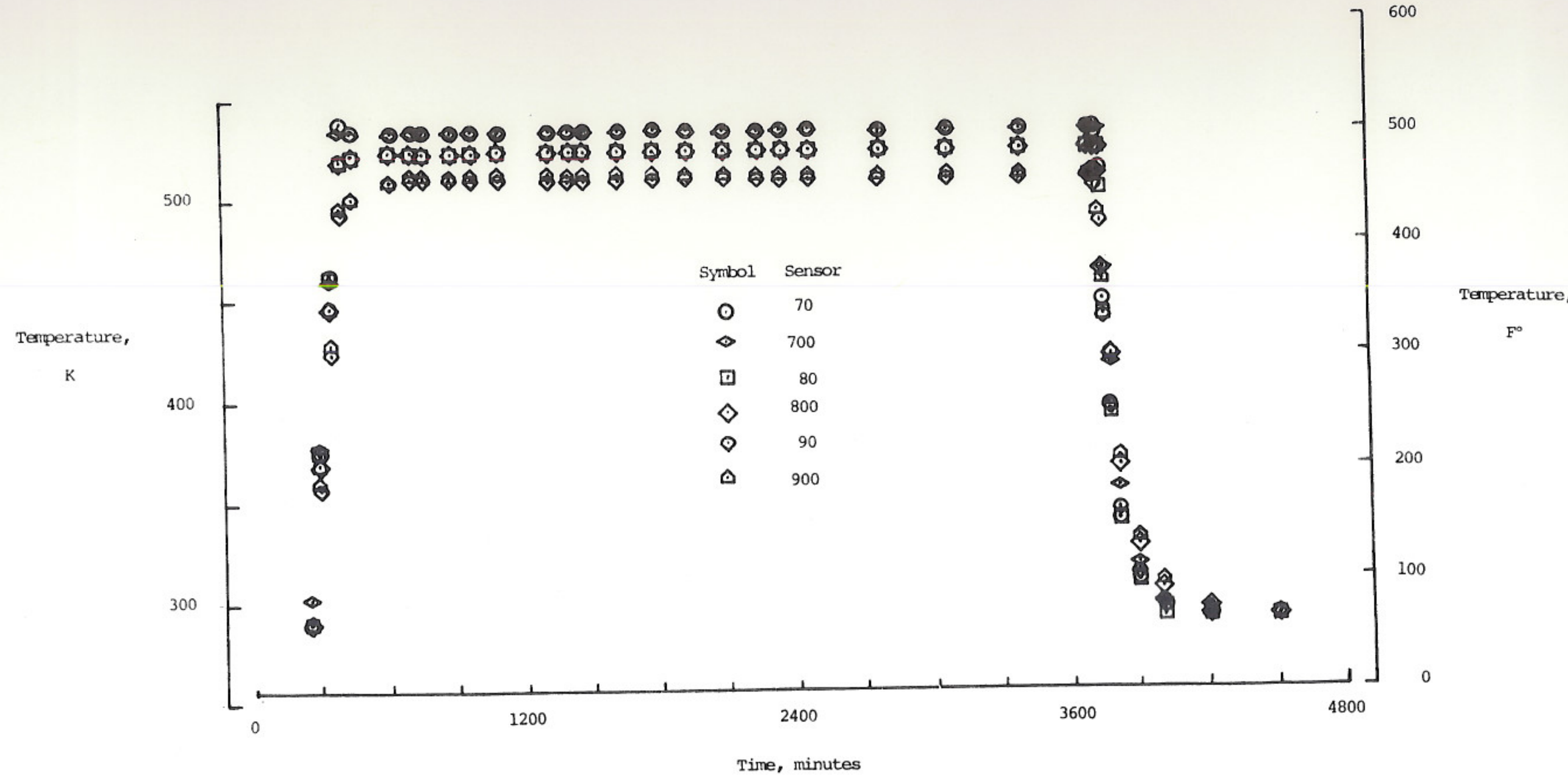
E 39018

Figure 5. Photograph of test set-up.



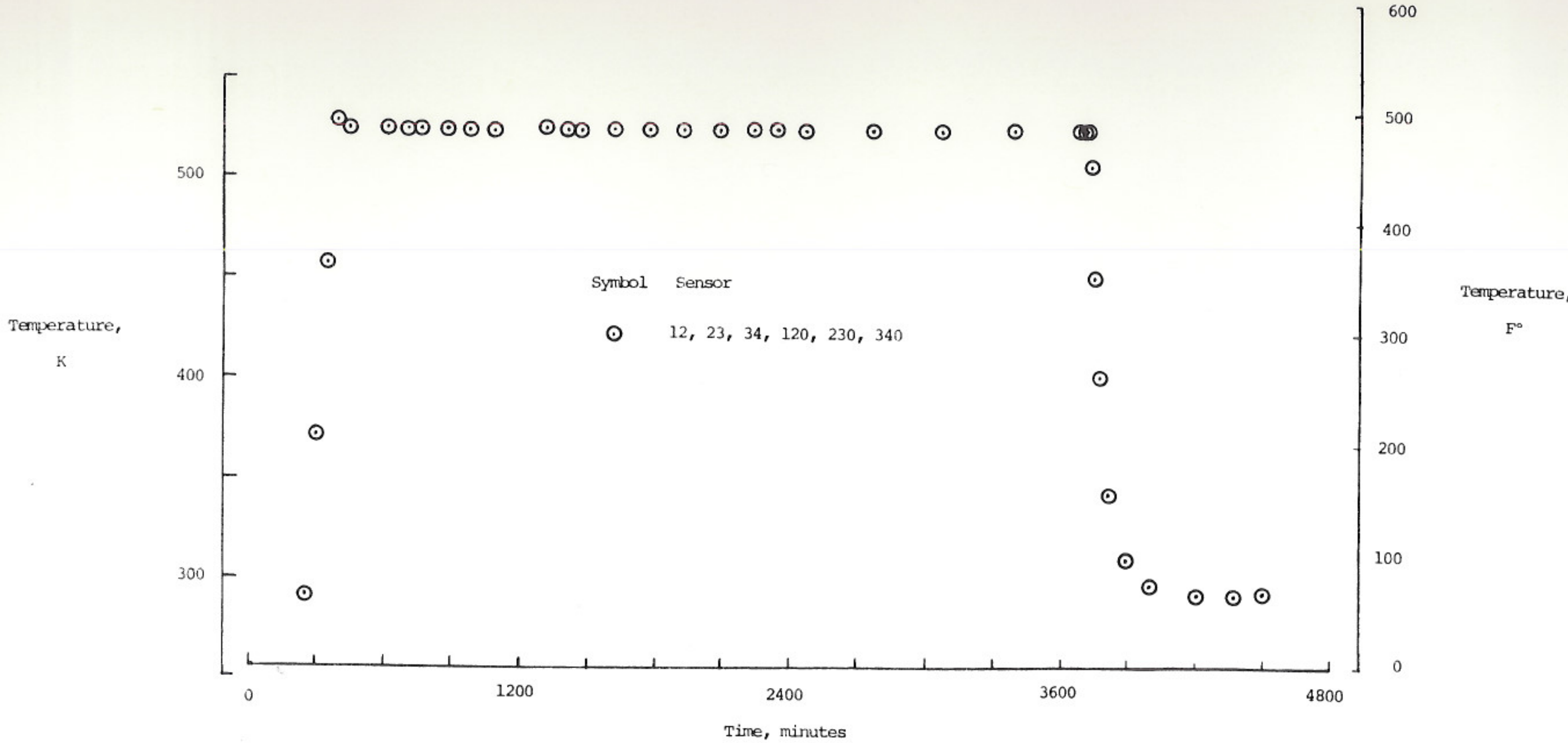
EVENT MARKER	EVENT	REMARKS
A	Heating begins.	Thermal stress ensues.
B	100 percent load applied.	Thermal and mechanical stress.
C	Rapid creep begins.	
D	Load reduced to 60 percent.	Lower creep rate begins.
E	Load increased to 80 percent.	Intermediated creep rate.
F	Load is removed.	
G	Heating is terminated.	
H	Structure returns to room temperature. temperature.	Residual strain due to creep is apparent.

Figure 6. Detail of test procedure.



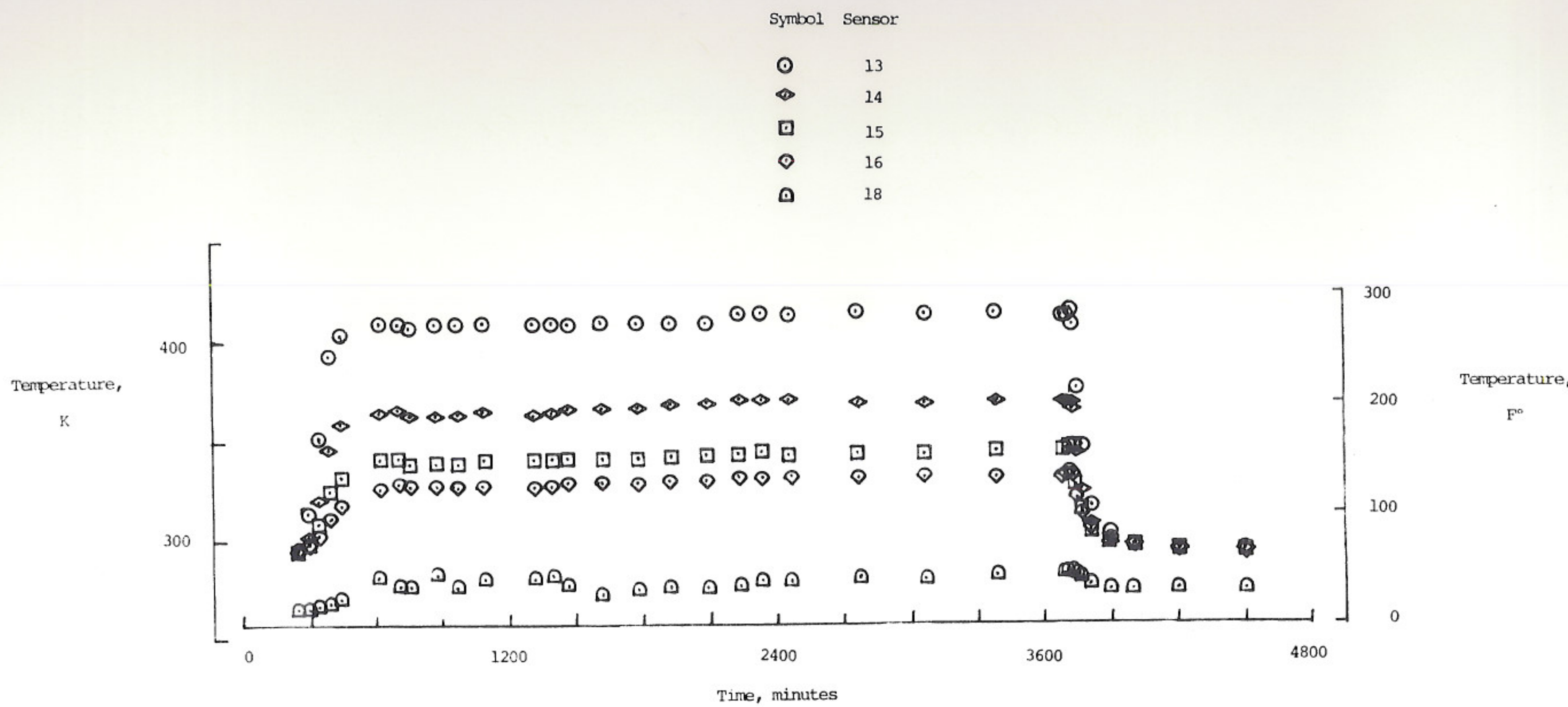
(a) Thermocouples 70, 700, 80, 800, 90, and 900.

Figure 7. Time-history of temperatures.



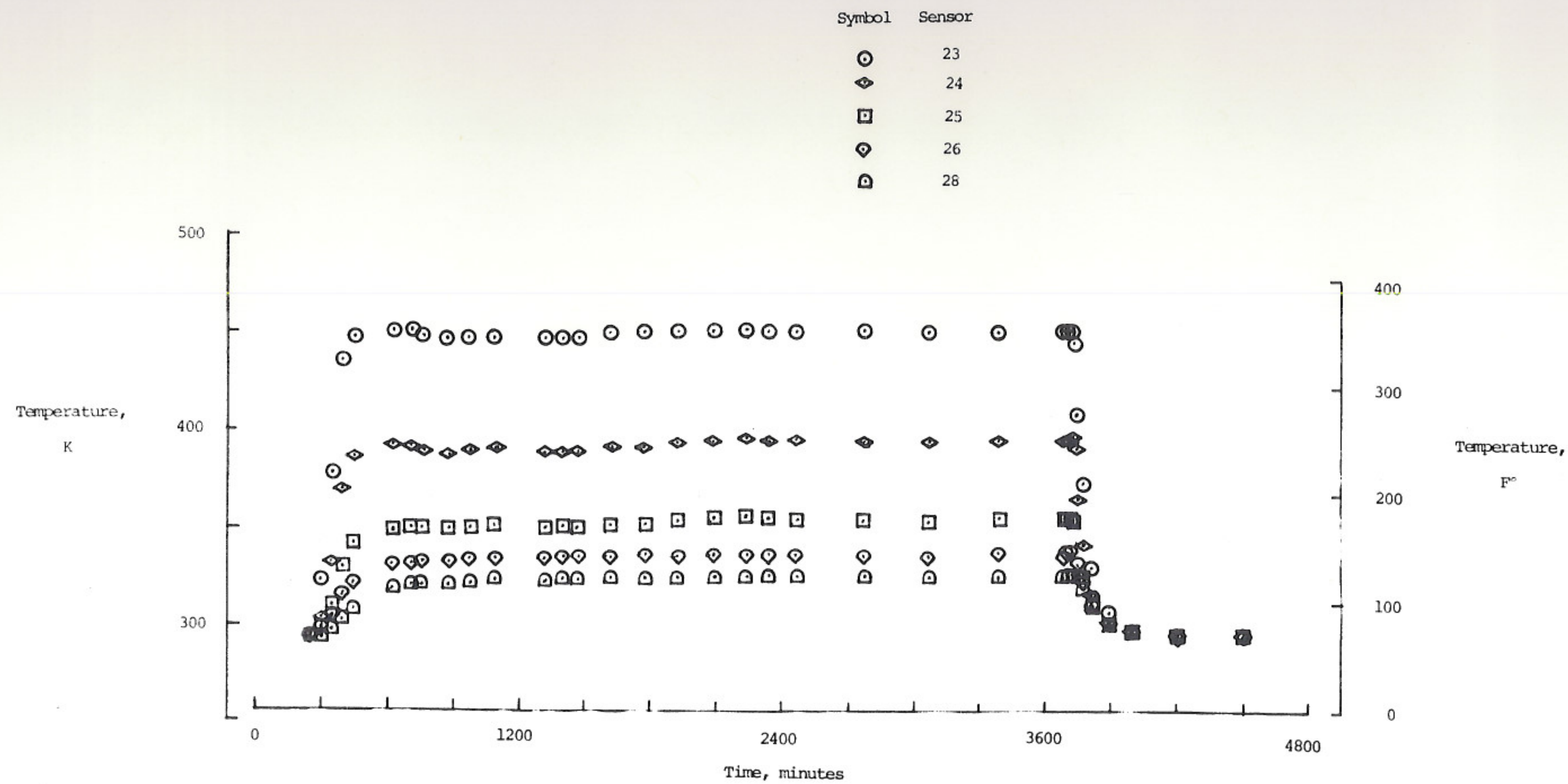
(b) Thermocouples 12, 23, 34, 120, 230, and 340.

Figure 7. Continued.



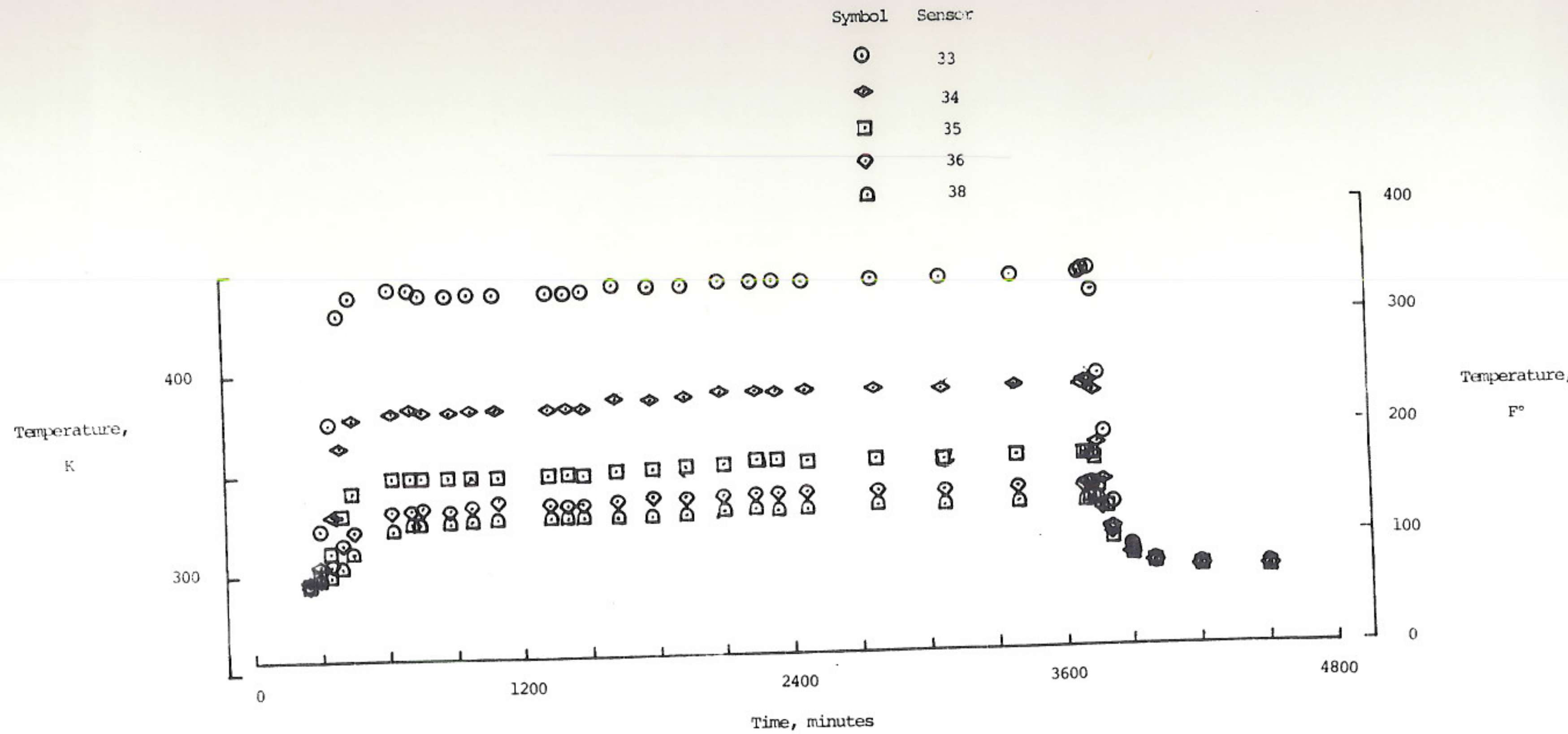
(c) Thermocouples 13, 14, 15, 16, and 18.

Figure 7. Continued.



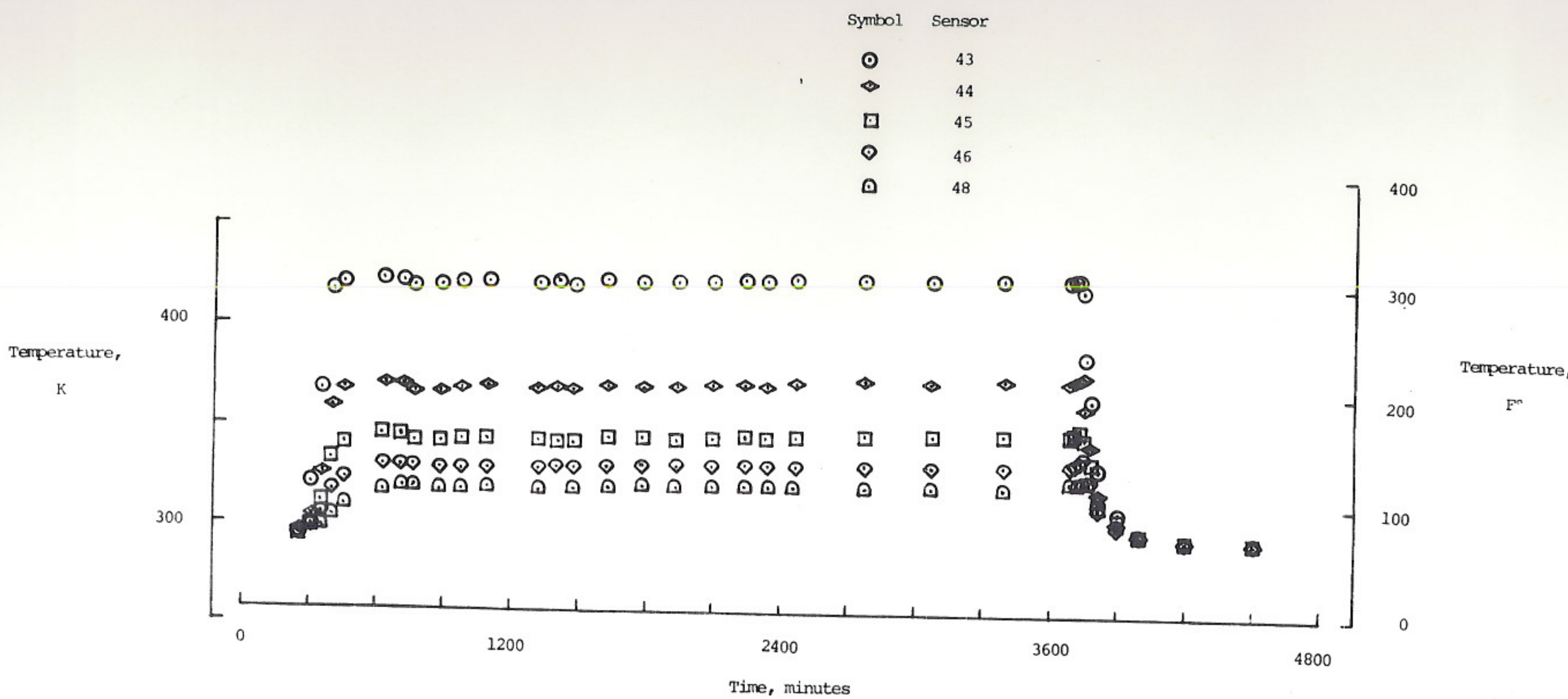
(d) Thermocouples 23, 24, 25, 26, and 28.

Figure 7. Continued.



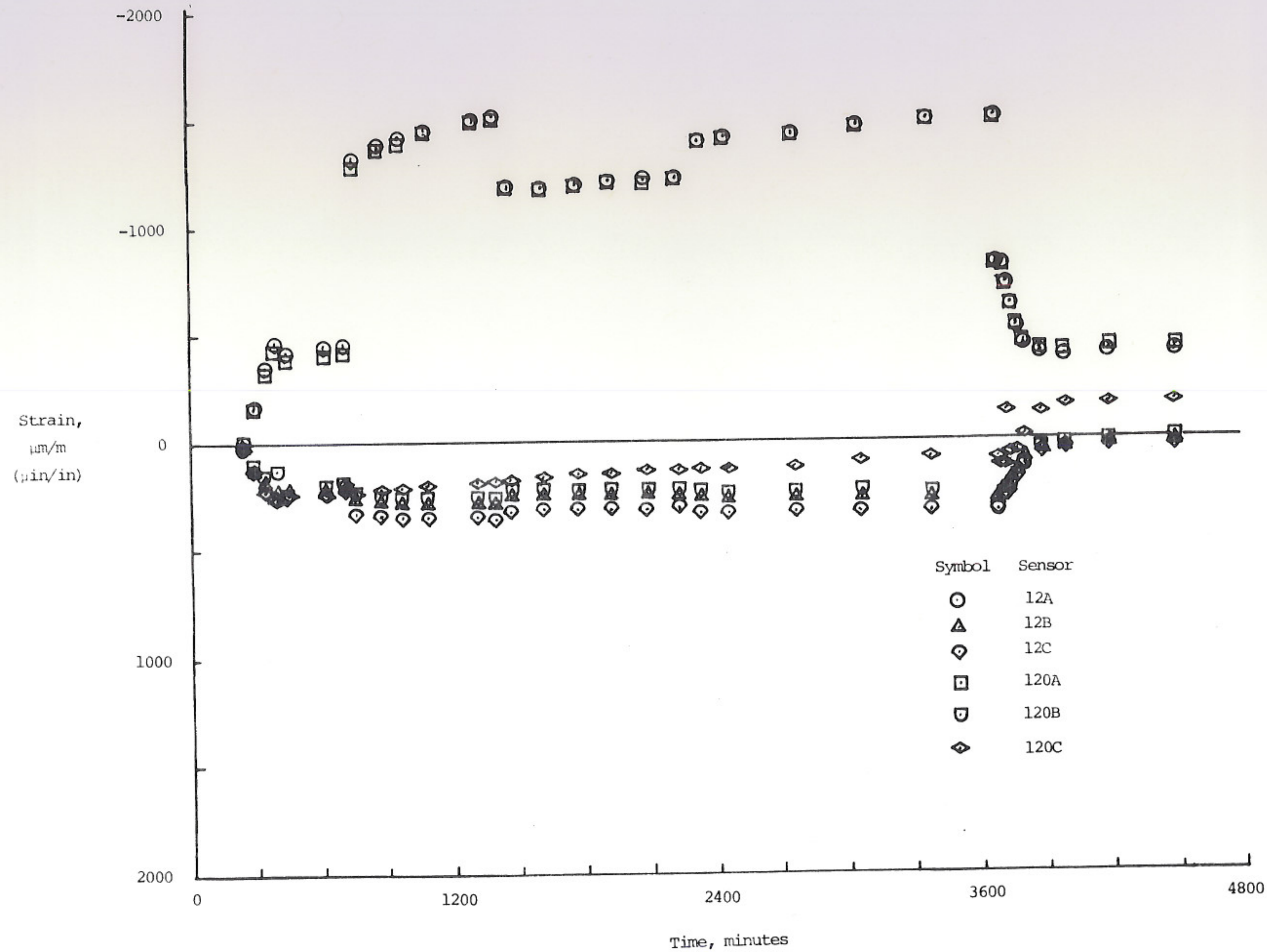
(e) Themocouples 33, 34, 35, 36, and 38.

Figure 7. Continued.



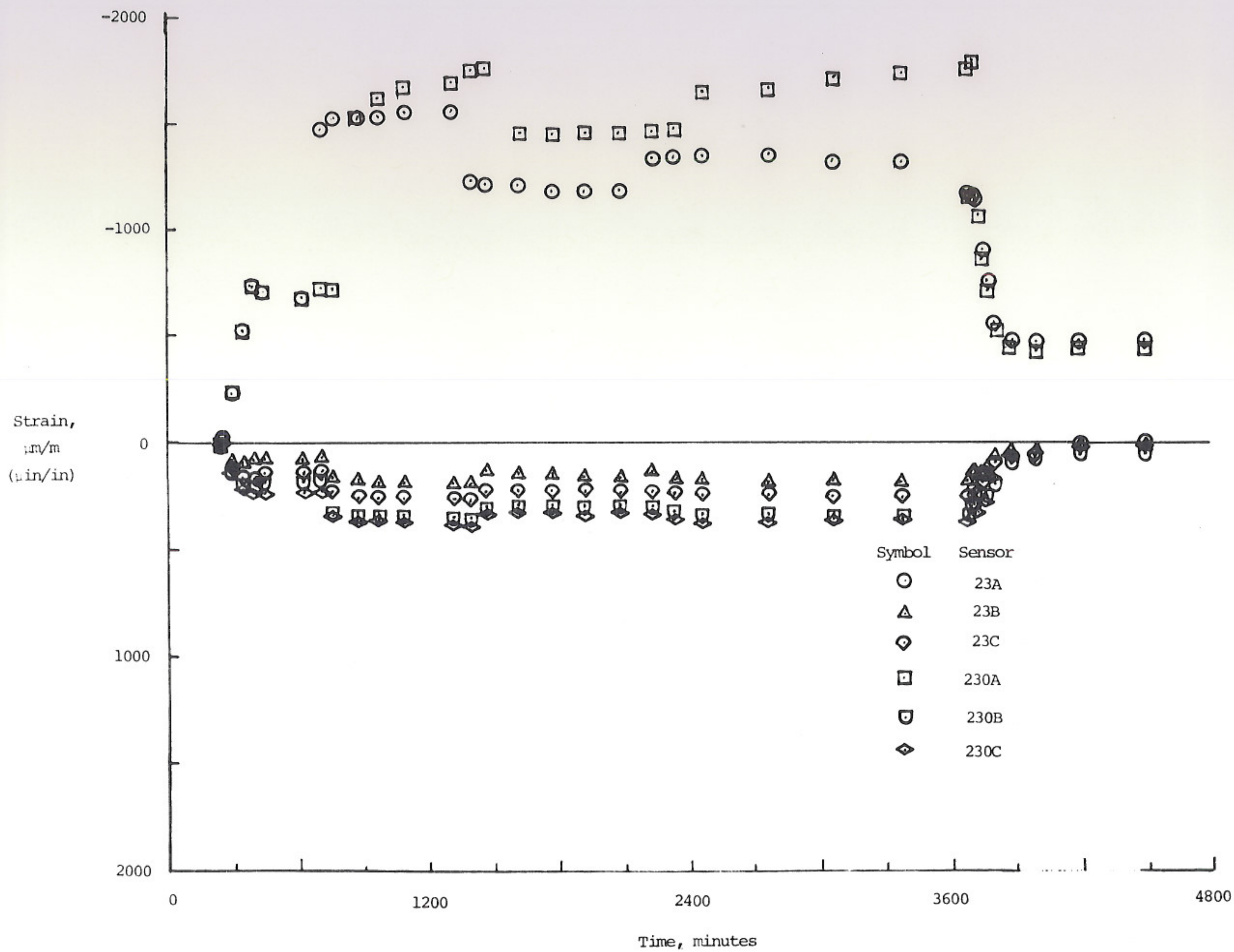
(f) Thermocouples 43, 44, 45, 46, and 48.

Figure 7. Concluded.



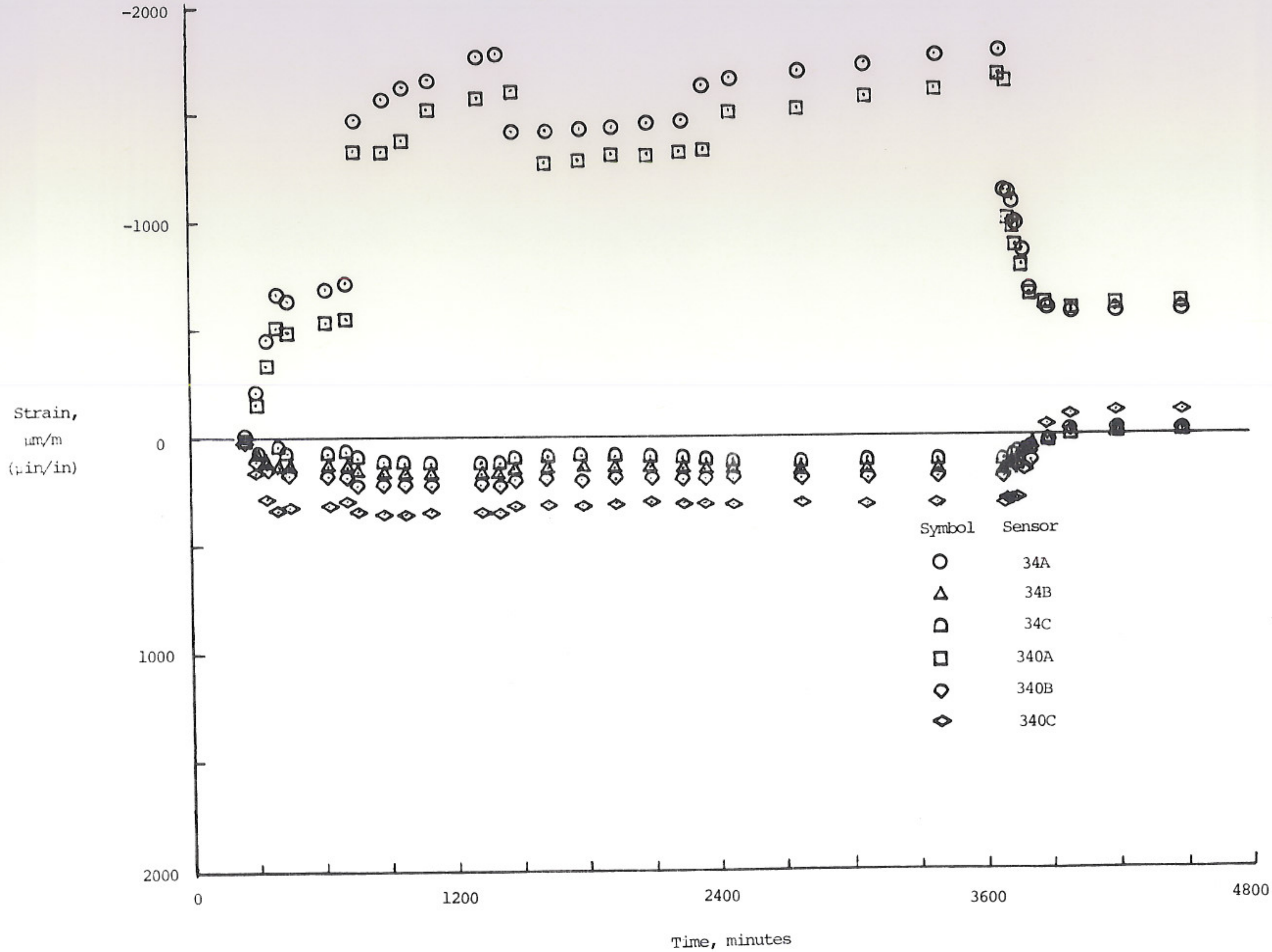
(a) Skin rosettes 12 and 120.

Figure 8. Time-history of skin rosette strains.



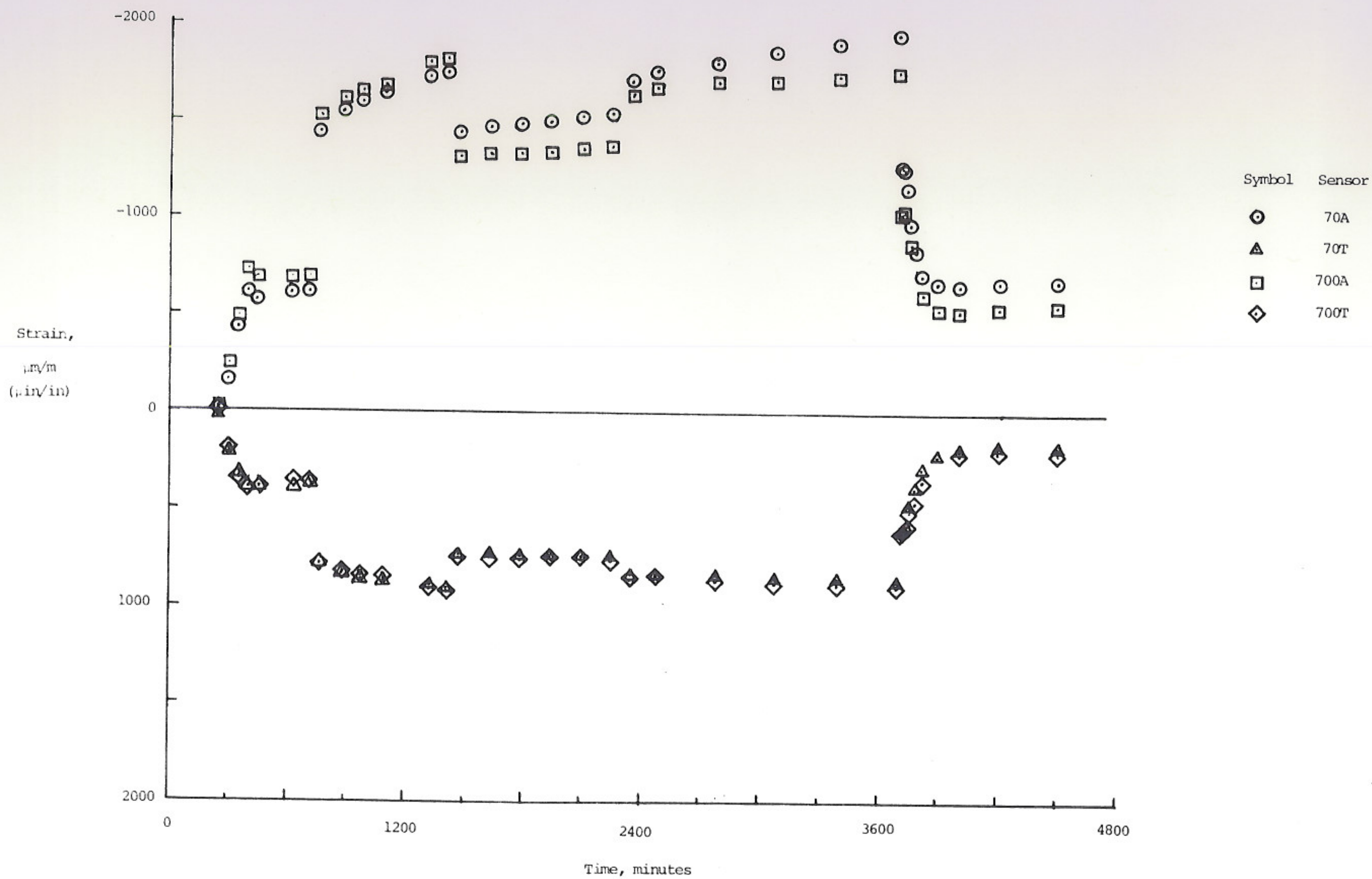
(b) Skin rosettes 23 and 230.

Figure 8. Continued.



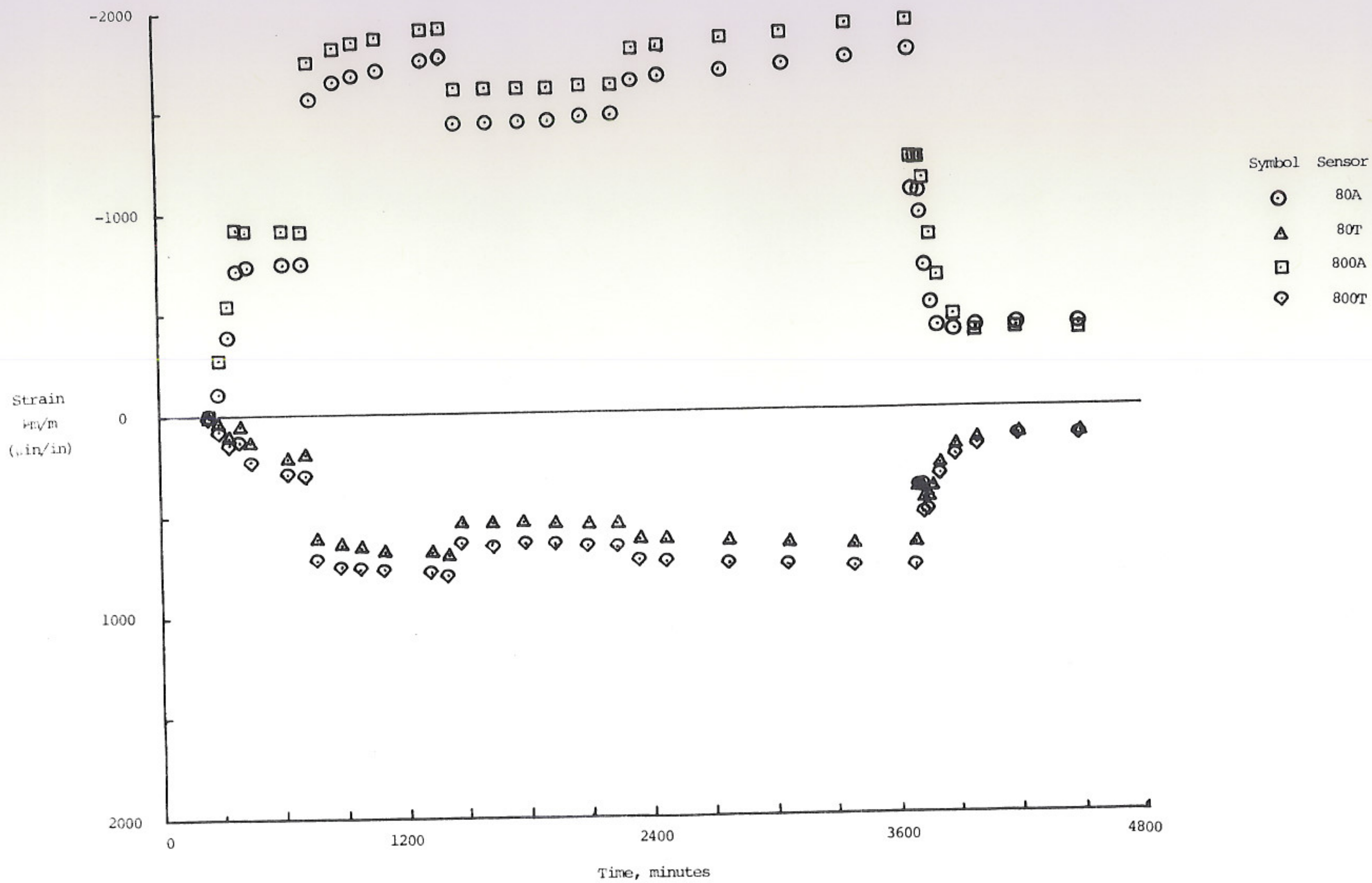
(c) Skin rosettes 34 and 340.

Figure 8. Concluded.



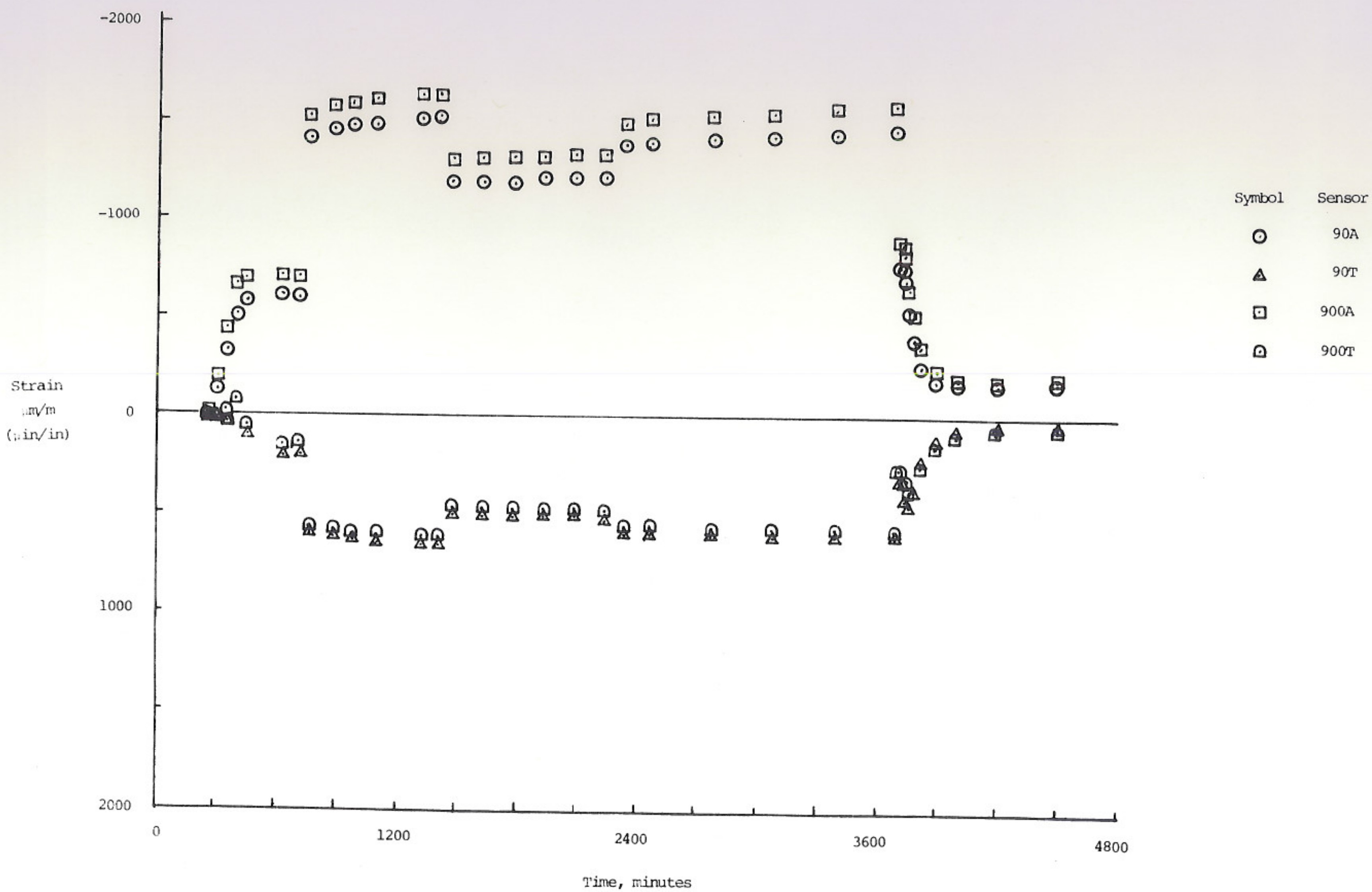
(a) Skin gages 70A, 70T, 700A, and 700T.

Figure 9. Time-history of skin tee strains.



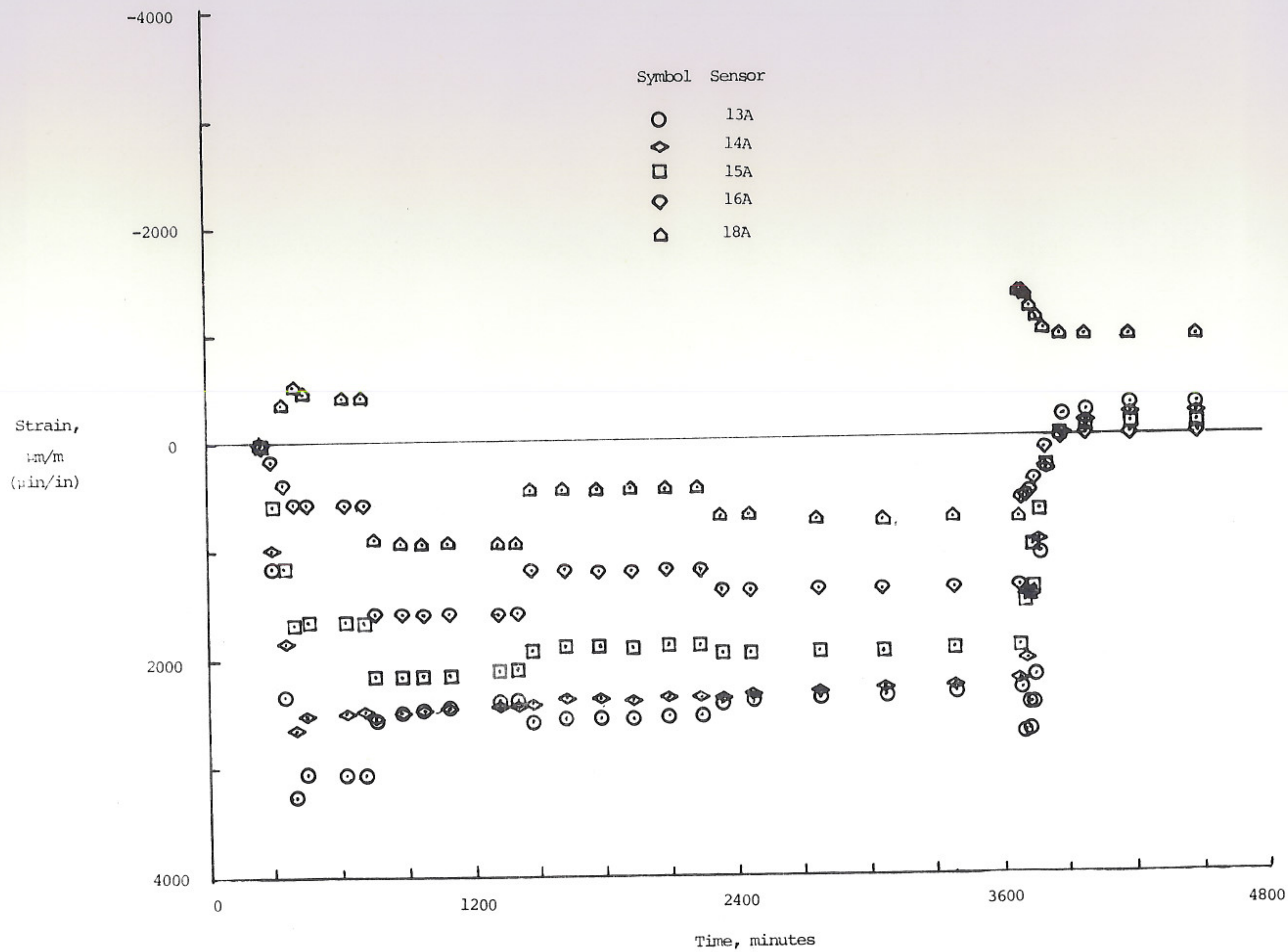
(b) Skin gages 80A, 80T, 800A, and 800T.

Figure 9. Continued.



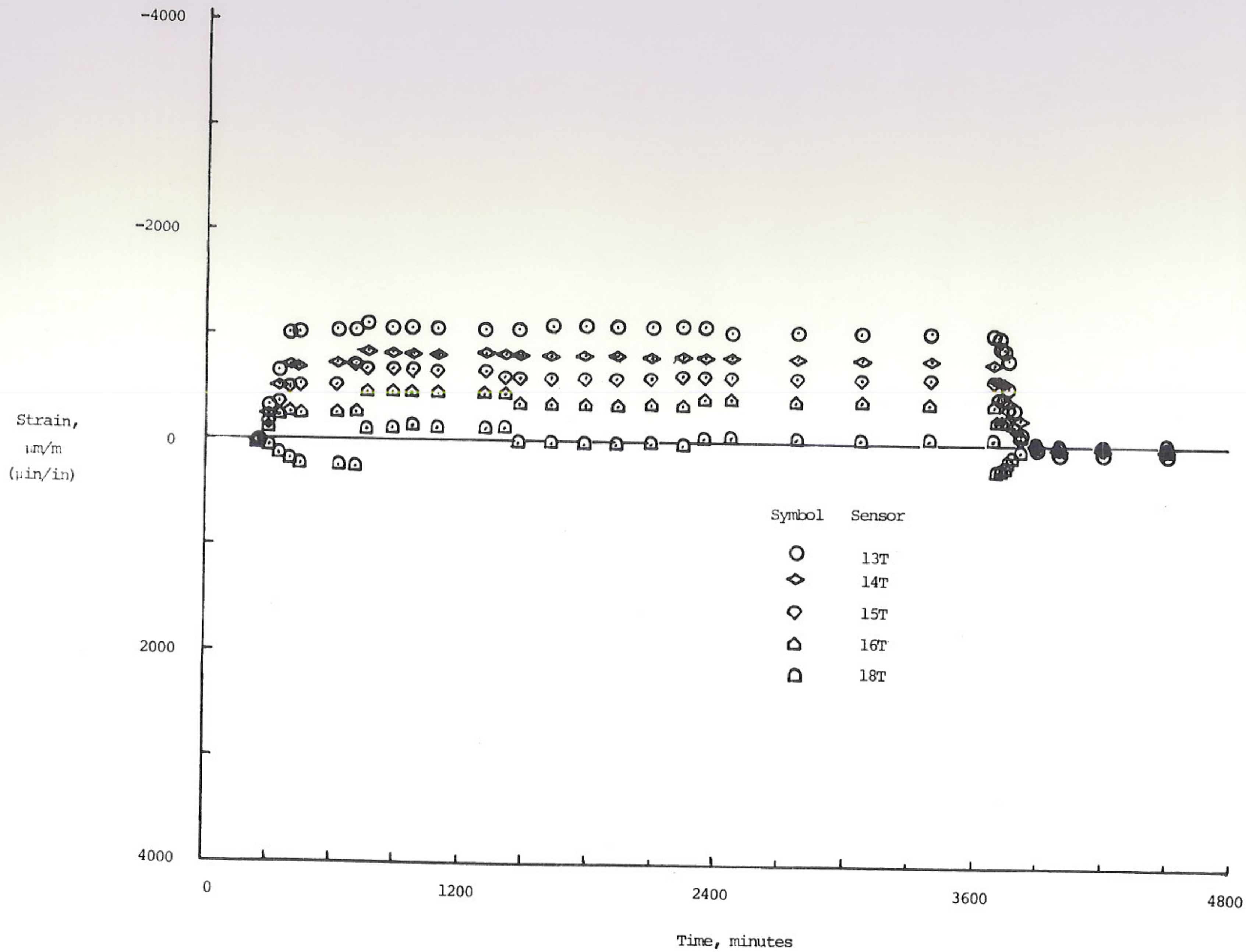
(c) Skin gages 90A, 90T, 900A, and 900T.

Figure 9. Concluded.



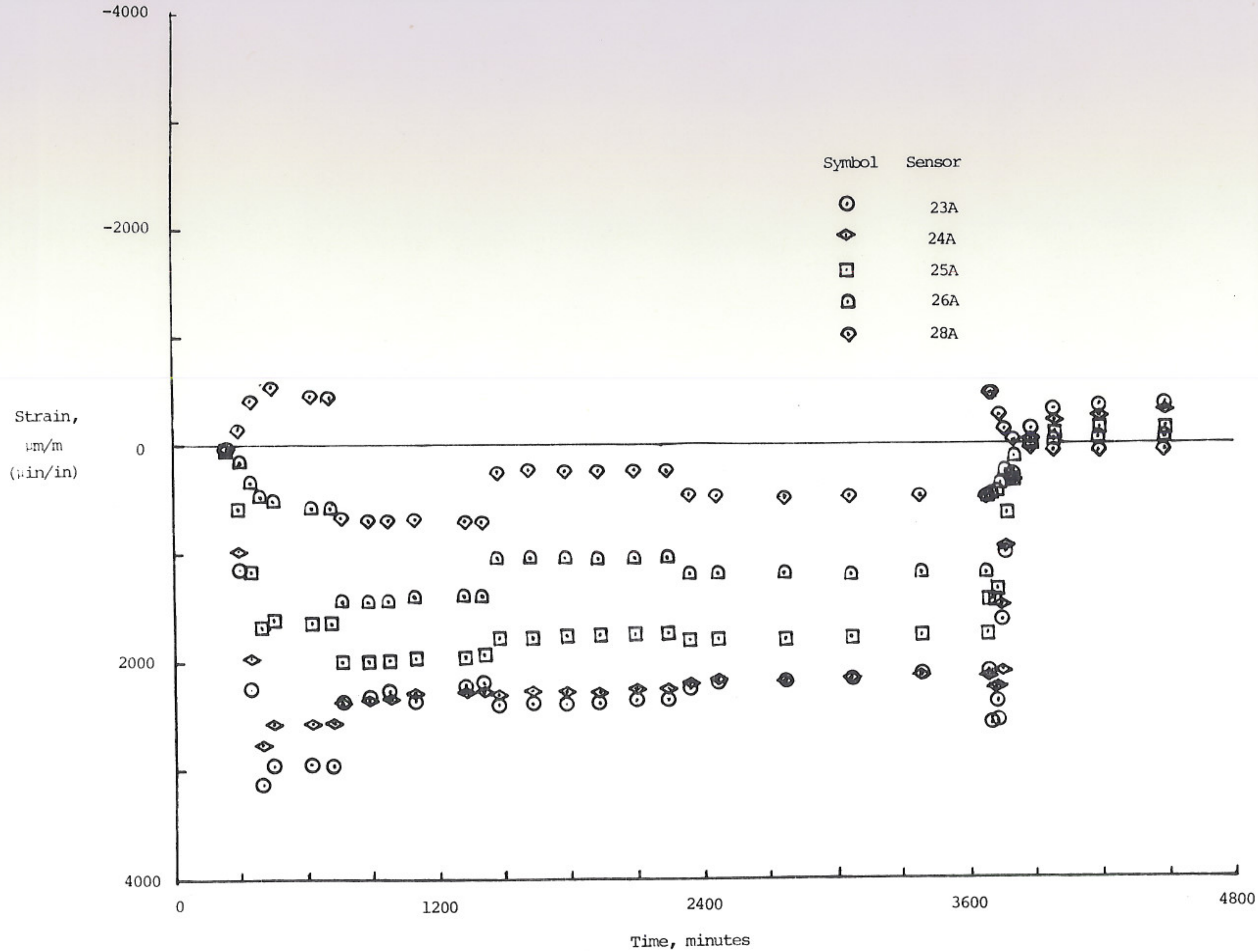
(a) Axial strain gages 13A, 14A, 15A, 16A, and 18A.

Figure 10. Time-history of frame number 1 strains.



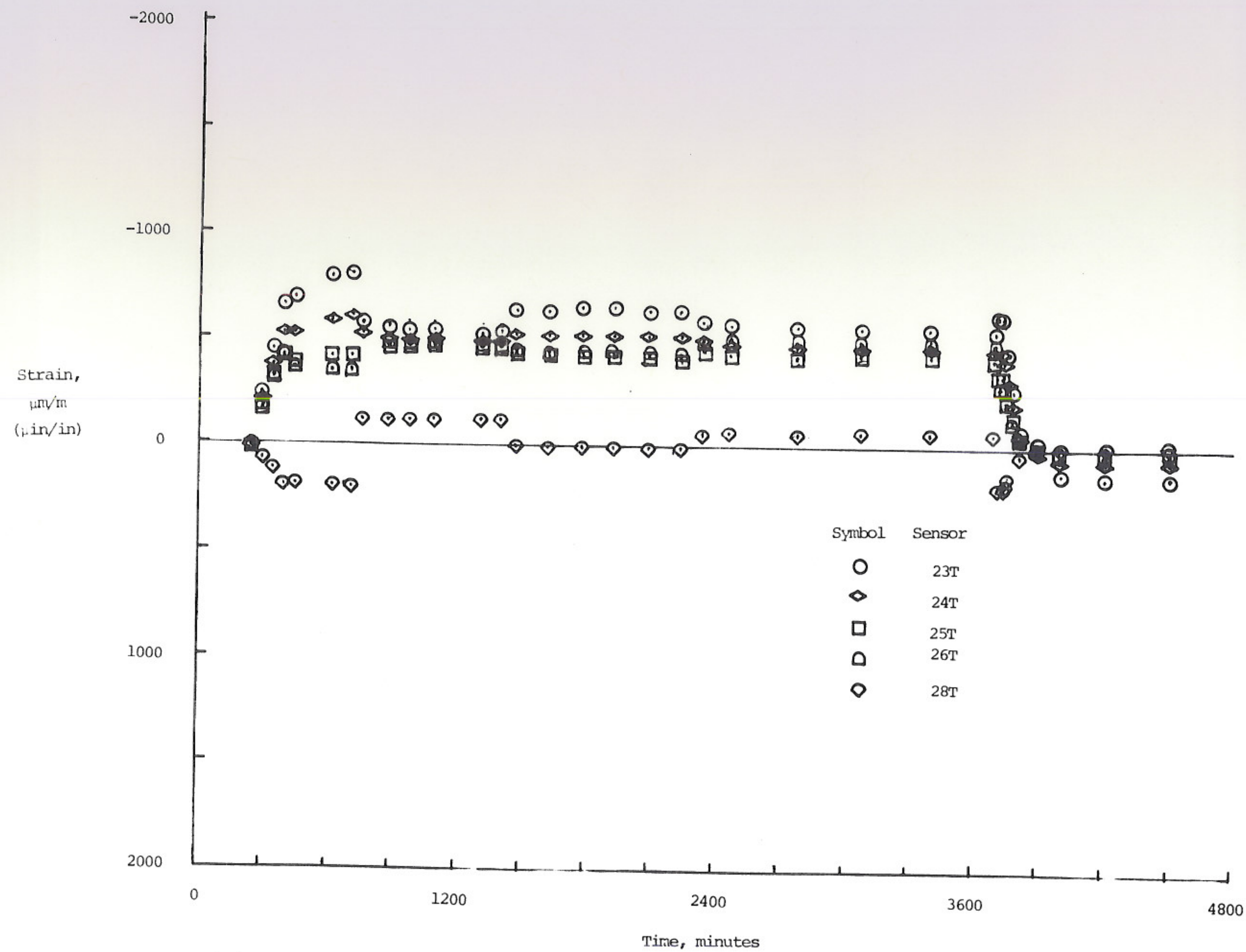
(b) Transverse strain gages 13T, 14T, 15T, 16T, and 18T.

Figure 10. Concluded.



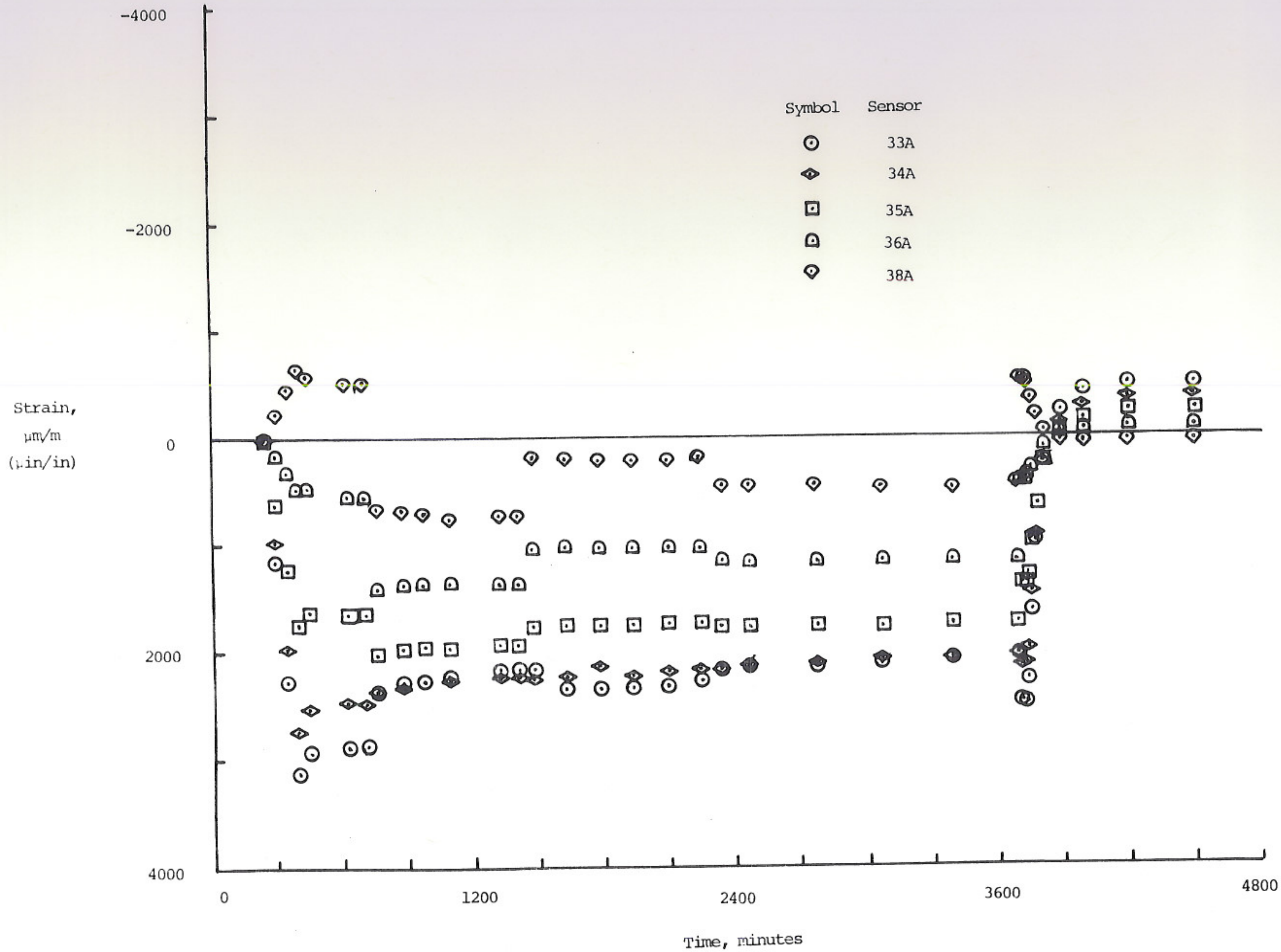
(a) Axial strain gages 23A, 24A, 25A, 26A, and 28A.

Figure 11. Time-history of frame number 2 strains.



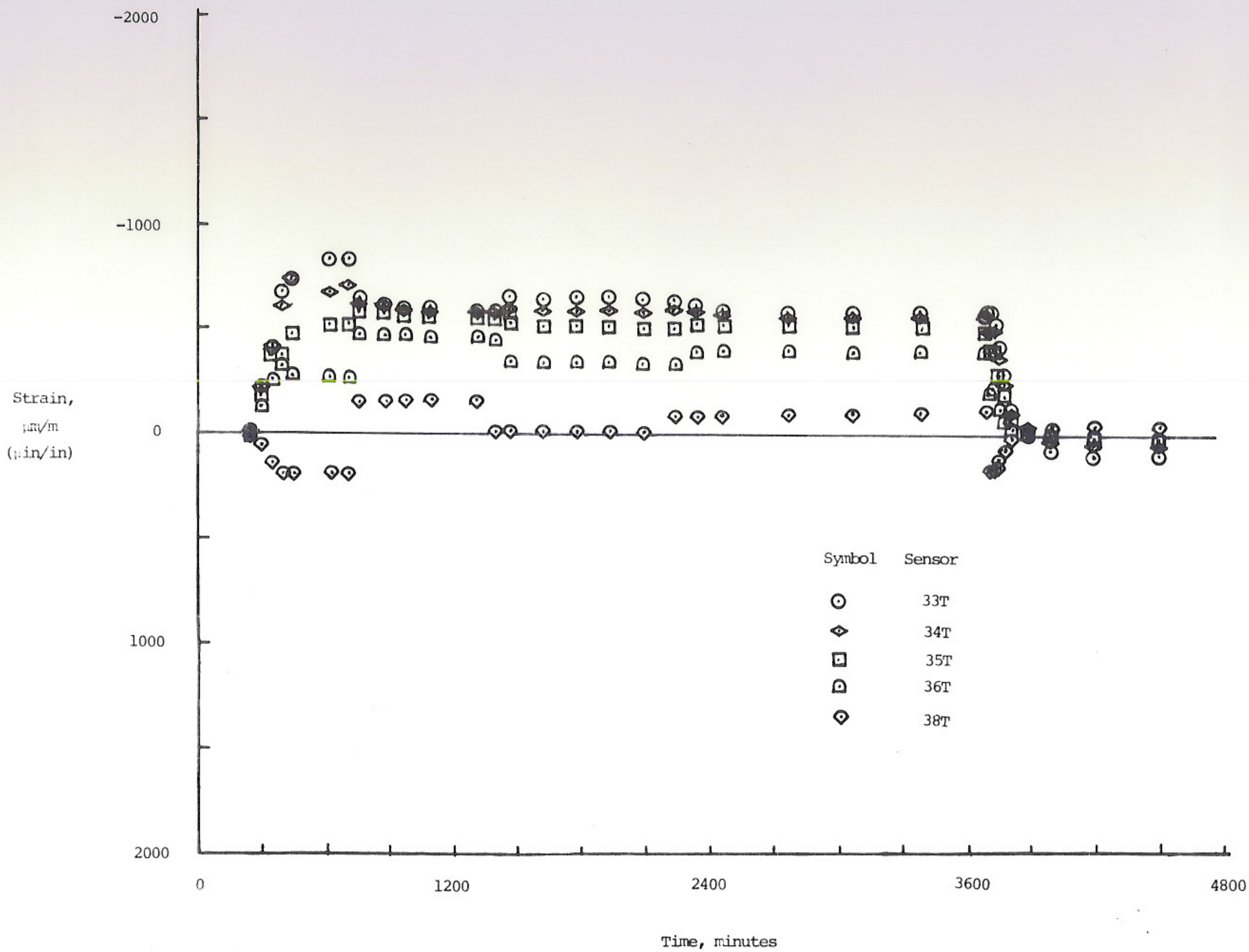
(b) Transverse strain gages 23T, 24T, 25T, 26T, and 28T.

Figure 11. Concluded.



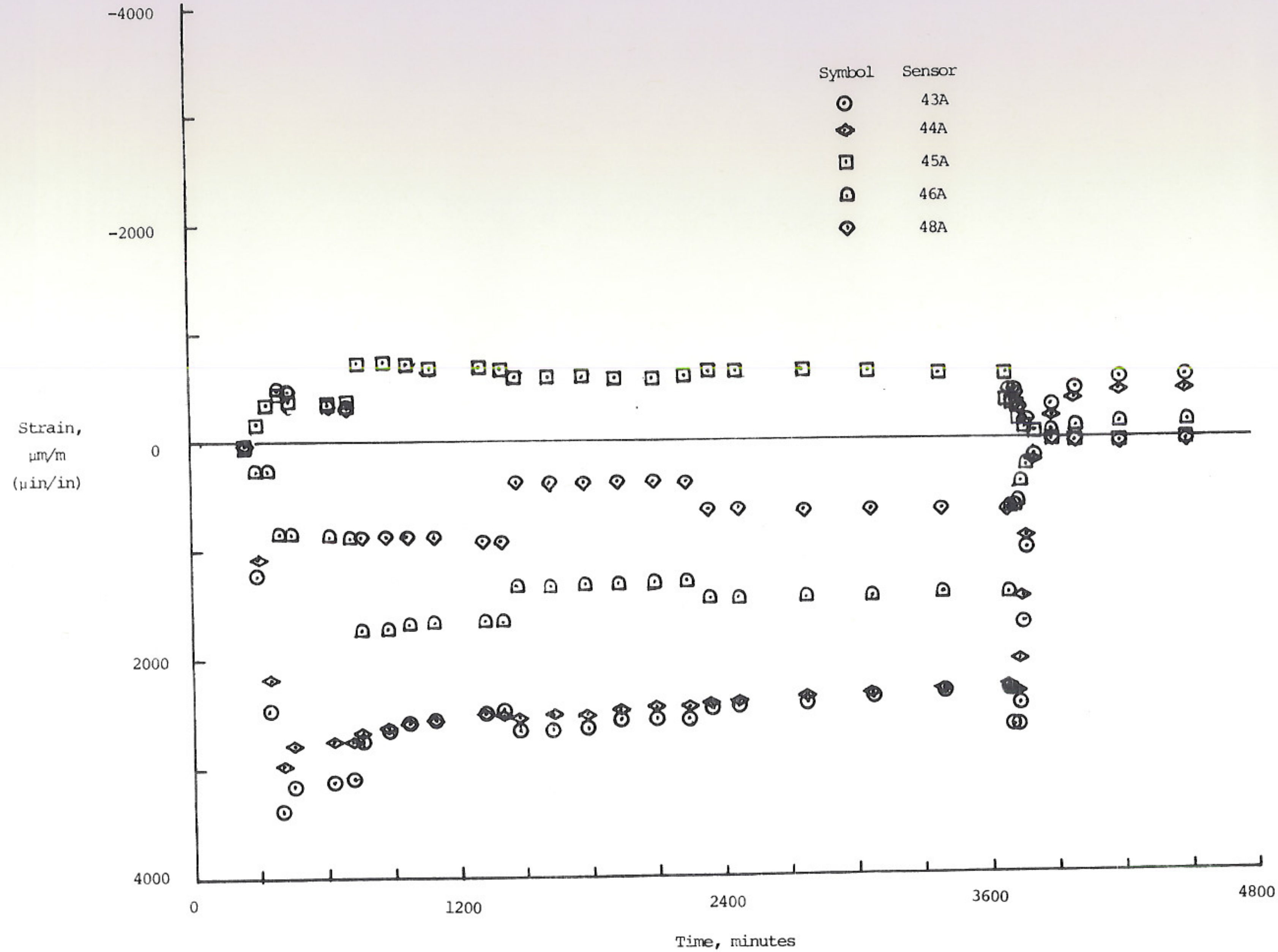
(a) Axial strain gages 33A, 34A, 35A, 36A, and 38A.

Figure 12. Time-history of frame number 3 strains.



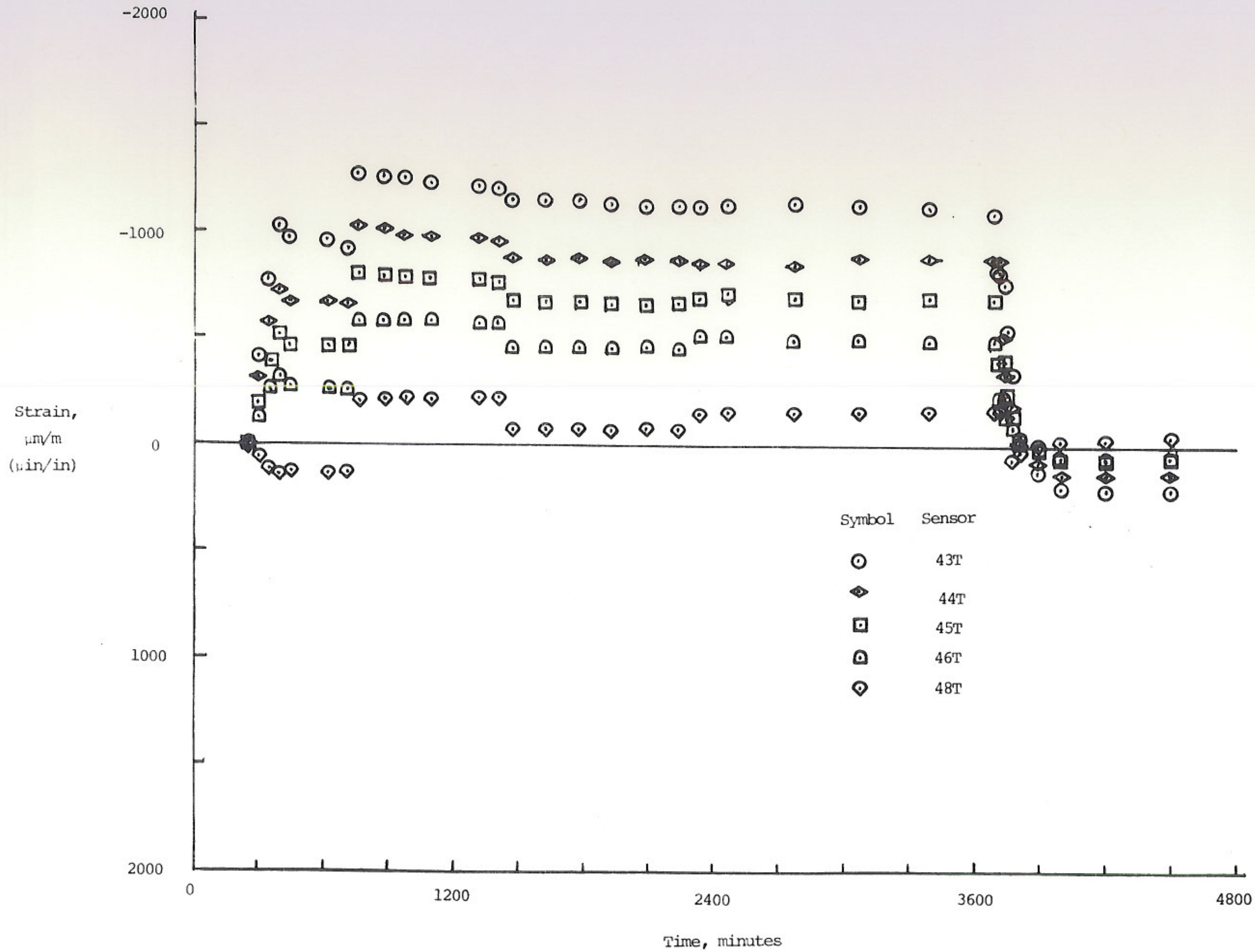
(b) Transverse strain gages 33T, 34T, 35T, 36T, and 38T.

Figure 12. Concluded.



(a) Axial strain gages 43A, 44A, 45A, 46A, and 48A.

Figure 13. Time-history of frame number 4 strains.



(b) Transverse strain gages 43T, 44T, 45T, 46T, and 48T.

Figure 13. Concluded.

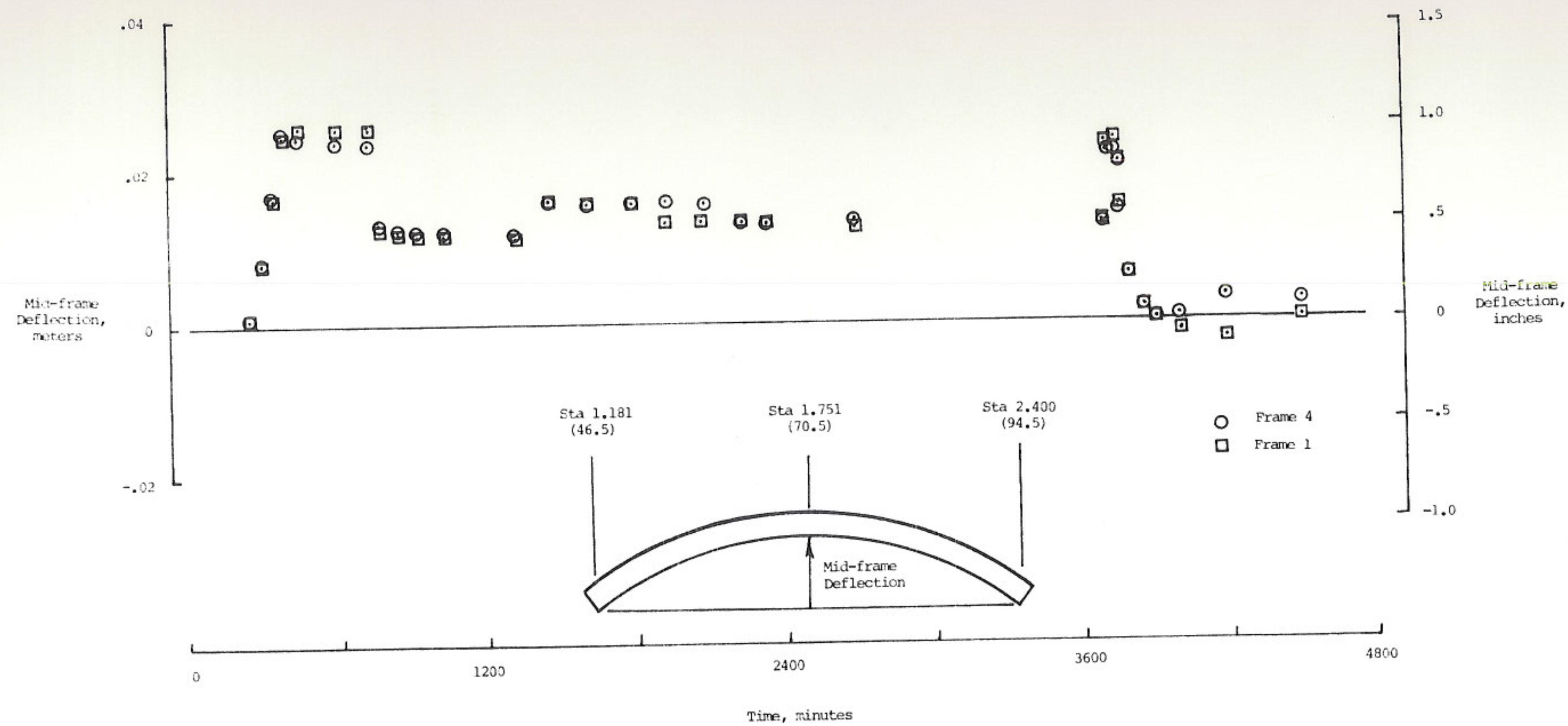


Figure 14. Time-history of deformations.

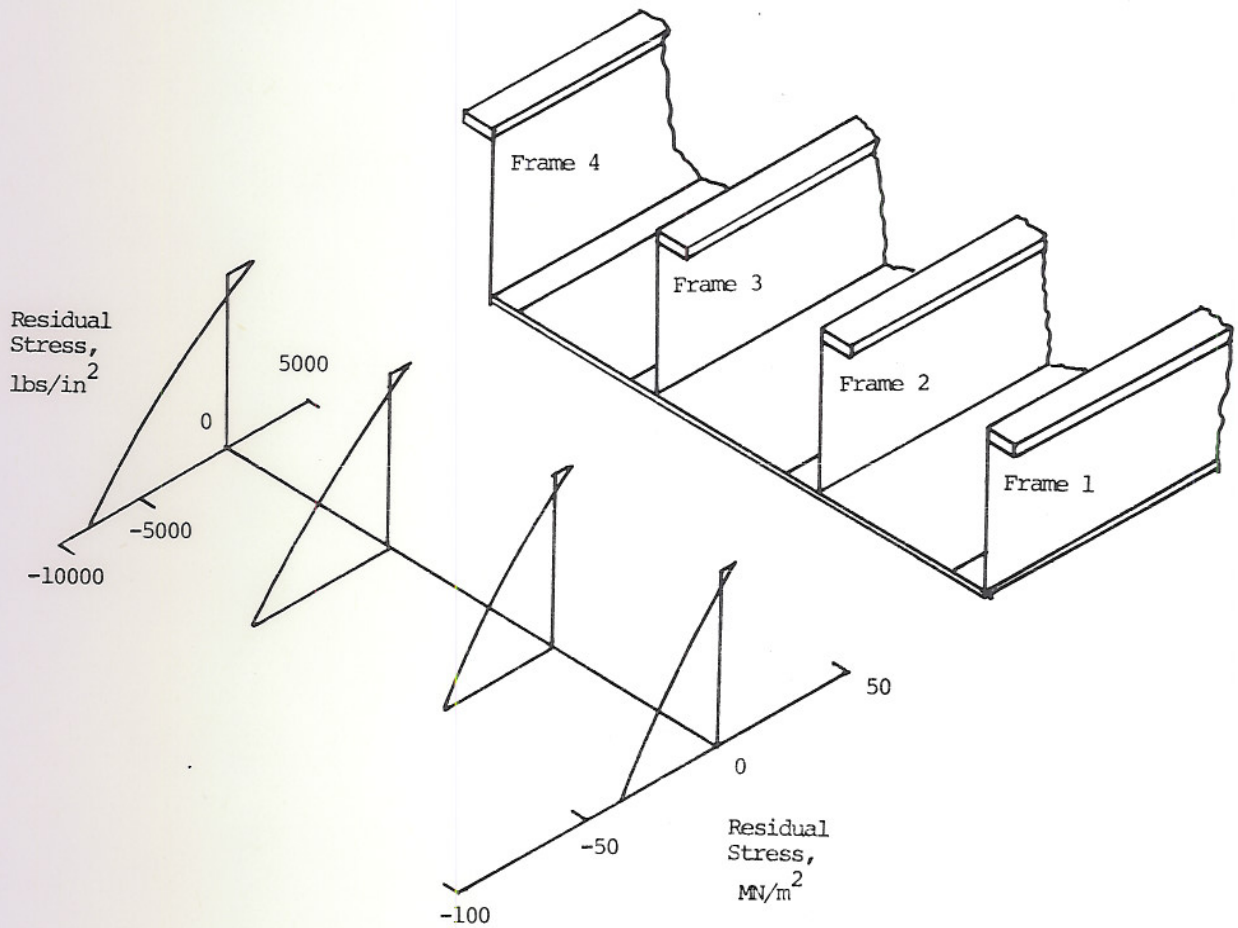


Figure 15. Residual frame stresses.

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16. Abstract

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